Economic Assessment of the Urban Heat Island Effect

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Prepared for

City of Melbourne

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Executive Summary

This report was commissioned by the City of Melbourne to develop an evidence-based economic assessment of the current and future costs associated with heat, heatwaves, and the intensification of the Urban Heat Island in the City of Melbourne. Melbourne's Urban Heat Island has been shown to be a significant contributor to peak temperatures within the Central Business District (CBD).

Based on hourly temperature data derived from both within the CBD area and a number of stations outside it, a UHI effect was derived over a range of temperatures. Effectively, when non-CBD areas experience a 30 degree day, the City experiences a 30.8 degree day – a UHI effect of 0.8 degrees C. This effect falls to about 0.5 degrees at 40 degrees C.

These effects are expected to be exacerbated by climate change. Under climate project modelling and the derived UHI effect, the CBD is expected to experience 2.2 additional days per year that are greater than 35 degrees C than in non-CBD areas, and an additional heatwave (defined as three sequential days greater than 35 degrees C) every ten years compared to non-CBD areas.

The impacts of this additional hot weather within the City is expected to produce a range of impacts on health, transport operation and infrastructure, energy demand and infrastructure, trees and animals, and crime.

The vast majority of this economic impact is as a result of heat-related deaths, reflecting the dangerous effect that extreme temperatures can have on human life (particularly the elderly and disadvantaged), the increasing number of such events as a result of climate change (and hence increasing number of heat-related deaths), and importantly, the high value that society places on preventing the loss of a human life.

The economic cost of increased energy demand in the warmer months is offset by the benefits of reduced energy demand due to warmer condition that the UHI creates during colder winter months.

The total economic cost to the community due to hot weather is estimated to be approximately $1.8 billion in present value terms. Approximately one-third of these impacts are due to heatwaves. Of the total heat impact, the Urban Heat Island effect contributes approximately $300 million in present value terms.

This is a significant cost, and given the range of impacts that were not possible to quantify, this estimate could be considered conservative. In particular, impacts on personal well-being could potentially be the greatest impact of higher temperatures resulting from the UHI, but are also the most difficult to quantify.

Sensitivity analysis found that the results are quite sensitive to assumptions and inputs pertaining to mortality and discount rate, indicating that it may be possible to increase the robustness of results with further understanding and refinement in these areas.

This study has some limitations in relation to availability of appropriate data and information as well as inherent uncertainties such as future population, urban form and climatic conditions.

Recommendations

Based on the research and findings of this analysis, the following is recommended:

- We recommend further efforts to obtain the existing datasets that could not be obtained for this study, particularly the full dataset of health impacts and crime by date for the past decade, so that a more robust correlation between impacts and temperatures can be developed. Obtaining similarly detailed attendance information for major events would also improve the analysis. Further research into impacts of high overnight temperatures and the role of the UHI in these would also be beneficial.

The economic impacts presented here indicate that the effects of the UHI are significant. Alone, however, they do not provide a case for action. The case for action must be made on an assessment of the reduction in impact possible by undertaking various actions, relative to the cost of these proposed actions. The assessment here provides a firm baseline for such a Cost Benefit Analysis. We therefore recommend that the information presented here be used in the development of a Cost Benefit Analysis of actions aimed at mitigating the UHI effect.

1.0 Introduction

1.1 Background

Urban heat islands (UHIs) affect the functioning, liveability and health of our cities. Climate change is expected to exacerbate these effects through increased temperatures – particularly through increases to the frequency and intensity of heatwave events. The impacts of a changing climate have been determined by using a range of factors including demographic changes, economic development and the structure and urban form of the city itself. Arising from these impacts are a variety of direct and indirect cost implications for the City of Melbourne and the community.

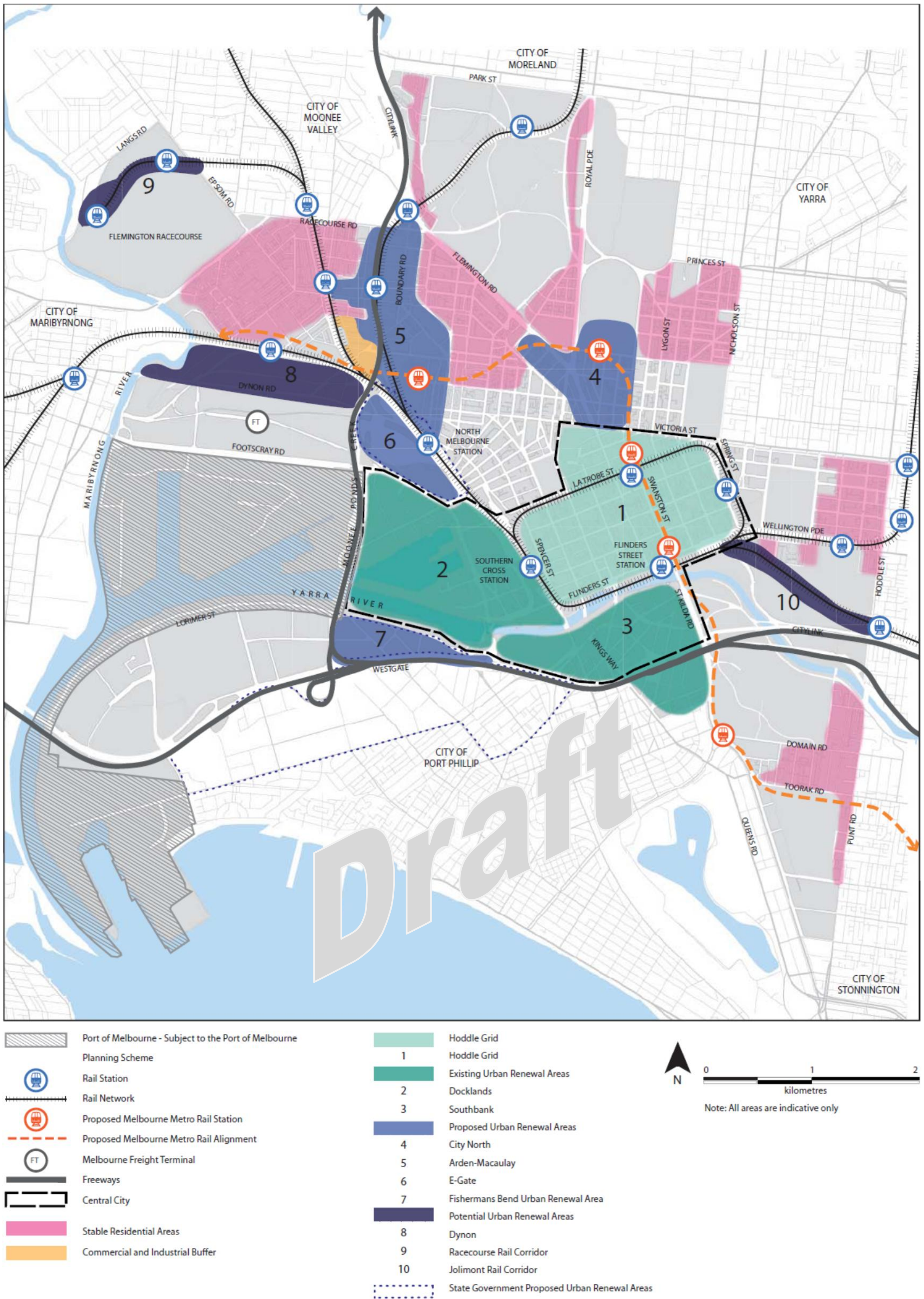
Council requires an evidence-based economic assessment of the current and future costs associated with the intensification of high temperatures weather and the UHI to inform robust cost-benefit analysis of mitigating actions including the Urban Forest Strategy, community heat wave planning and Council operations. For these initiatives to be successful, it is critical that the likely costs of UHI impacts are assessed in a transparent and consistent manner for Council to be able to demonstrate the potential economic benefits of adopting any UHI mitigation actions.

This economic assessment of heatwave and UHI impacts is a first step towards understanding the extent, in monetary terms, of the issue and as an important step towards an assessment of potential mitigation and adaptations options.

The City of Melbourne, as represented in Figure 1, was used as the boundary of the study for assessing the direct effects of heatwaves and the UHI. The temperature conditions in surrounding urban areas outside this boundary were used to determine the observed relative UHI effect in Melbourne.

The economic impacts of heatwaves and the UHI affect an extensive range of public and private sector stakeholders in the City of Melbourne. This study sought input from a broad range of these stakeholders in sourcing data and contextual inputs into the study.

Figure 1 Draft Growth Area Framework Plan for City of Melbourne Municipal Strategic Statement



1.2 Purpose

The purpose of this study is to provide an economic assessment of the impacts of heatwaves and the Urban Heat Island (UHI) effect within the City of Melbourne.

The assessment is therefore focussed on the following:

- the incremental effects on temperatures within the City resulting from heatwaves and the UHI
- the incremental impacts that heatwaves and the UHI have on:
    - Health
    - Transport operation and infrastructure
    - Energy demand and infrastructure
    - Anti-social behaviour
    - Trees and animals
    - Major Events
    - Other impacts.
- the effects that climate change, population growth, and urban development have on the UHI and its consequential impacts.

The study is undertaken using two climate change scenarios: a high greenhouse gas emission scenario (A1FI), and a lower greenhouse gas emission scenario (A1B).

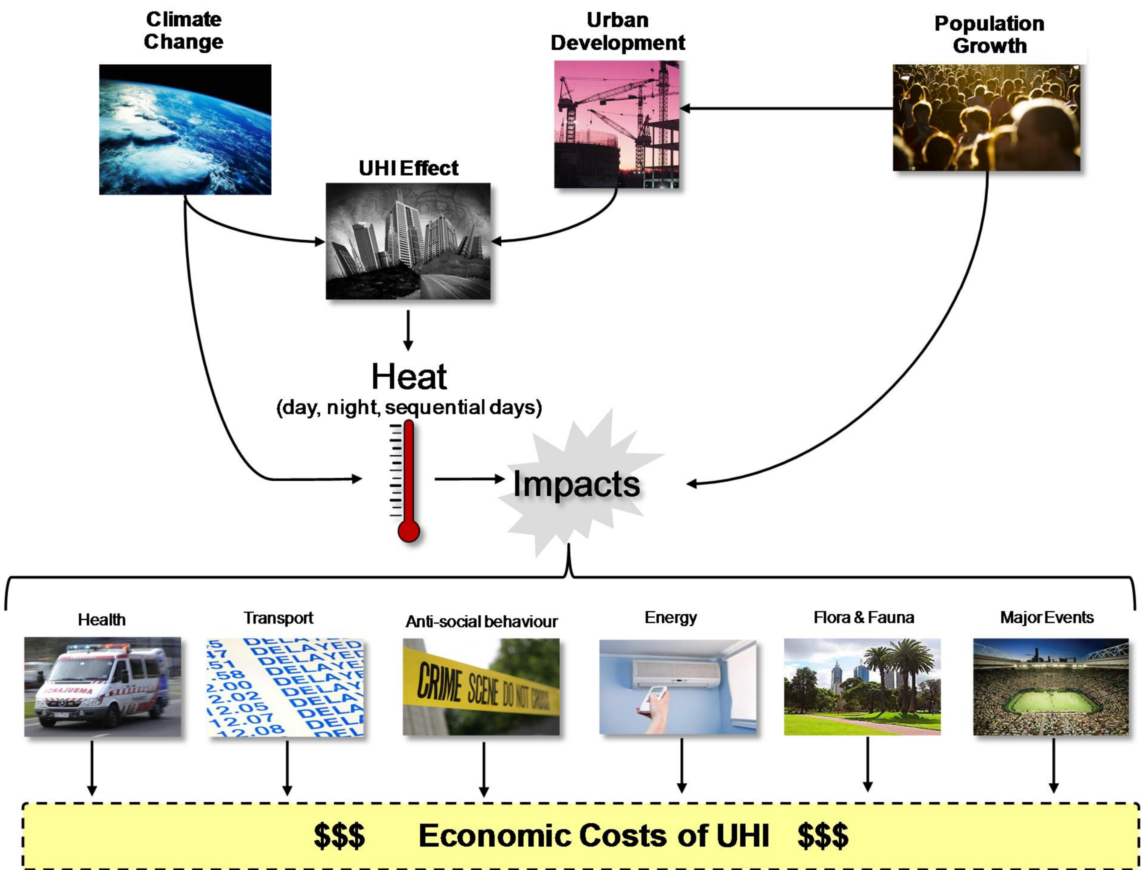
Impacts are monetised wherever possible and projected out to 2051, before conducting Discounted Cash Flow techniques are applied to estimate the Net Present Value of UHI Impacts.

1.3 Overview

1.3.1 Assessment methodology

An overview of the assessment methodology is presented diagrammatically in Figure 2.

Figure 2 Overview of study methodology



1.3.2 Structure of the Report

Beyond this introductory section, the report is structured in the following way:

- Section 2 discusses the underlying mechanism of the Urban Heat island effect, and the role of climate change in influencing the urban environment, along with a discussion of climate models used for this assessment
- Section 3 discusses our investigation of Melbourne's UHI effect, and our findings from the analysis of Melbourne temperature data
- Section 4 describes the impacts on community assets and values as a result of increased temperatures
- Section 5 discusses our analysis of the economic impacts of the UHI effect
- Section 6 discusses conclusions, limitations and recommendations arising from the study
- Section 7 lists the references used for this study

2.0 The Urban Heat Island Effect

2.1 Introduction

The Urban Heat Island (UHI) effect generates a range of negative and positive impacts to the economic prosperity of the City of Melbourne. To understand the impact of UHI now and in the future within a changing climate the following elements need to be considered:

- The extent of changing temperature conditions into the future
- The influence of an increasing population
- The changing characteristics of the urban form over time.

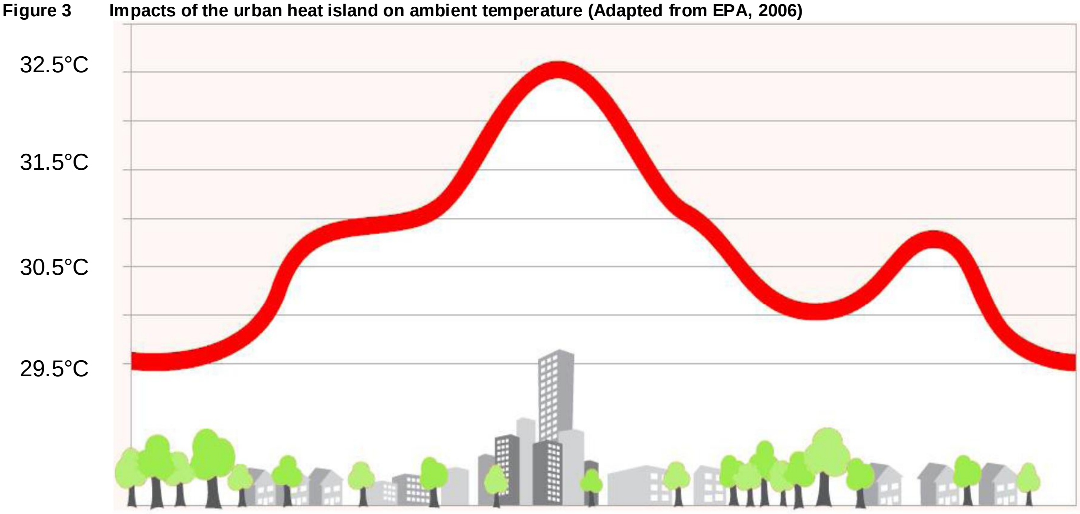
The following sections discuss and outline these considerations in the context of how they have been applied in this study.

2.2 Description of the Urban Heat Island Effect

The urbanization has radically transformed environments from native vegetation or farmland to largely built up areas. The thermal storage capacity and the thermal profile of urban areas are now dramatically different from adjacent non-CBD areas. This is known as the Urban Heat Island (UHI) effect. Local and international studies have found that the UHI effect can add between 1°C to 6°C to ambient air temperature (BoM 1997, US EPA 2005). The study undertaken here for the City of Melbourne has found a UHI effect at the lower end of this range, as discussed in Section 3.0. This may be partly due to the fact that the non-CBD weather stations used for the analysis include those situated within built-up areas (although significantly less than the CBD), that consequently retain heat and reduce the differential between CBD and non-CBD temperature measurements.

Figure 3 shows the intensification of UHI for different types of urban areas.

Figure 3 Impacts of the urban heat island on ambient temperature (Adapted from EPA, 2006)



The UHI effect exacerbates the absorption of heat during daytime and its release during night time. It is significantly increasing night time minimum temperature (EPA, 2006).

2.3 Changing climatic conditions

The influence of a changing climate on UHI in the City of Melbourne was assessed using observed climate changes and future climate change projections. Future climate change will exacerbate the impacts of UHI by increasing maximum temperatures and reducing minimum temperatures.

The projected future changes in climatic conditions were determined by selection of:

- greenhouse gas emissions scenarios
- global climate model projections
- time-frames assessed.

In 2007 the Intergovernmental Panel on Climate Change (IPCC) released their Fourth Assessment Report, concluding that:

- warming of the climate system is unequivocal
- humans are very likely to be causing most of the warming that has been experienced since 1950
- it is very likely that climatic changes will continue well into the future, and that they will be larger than those seen in the recent past (IPCC, 2007).

The Earth's average temperature increased by approximately 0.7°C over the past century , whilst Australia's average temperature increased by 0.9°C between 1910 and 2009 Most of this increase occurred after 1950 (approximately 0.7°C) and the past decade (2002 – 2011) was the warmest on record. Since 1910, overnight minimum temperatures have been increased more than daily maximum temperatures (1.1°C and 0.75°C respectively)(CSIRO, 2011). In Victoria, average temperature increased by just under 0.6ºC from 1950 to 2005 (CSIRO, 2007). The frequency and severity of very hot days (greater than 40 degrees) in Victoria has also increased since 1910 (Gallant and Karoly, 2010). These extreme events include the unprecedented 3-day heatwave in January 2009. Long term increases in Australian temperatures, including temperatures in Victoria have been attributed in part to increases in greenhouse gas emissions.

In the future, Victoria is expected to warm at a slightly faster rate than the global average (CSIRO, 2007). Climate change projections for temperature prepared by CSIRO suggest that the future climate of Victoria is likely to be characterised by:

- higher average, maximum and minimum temperatures, particularly in spring and summer
- a more frequent occurrence of extreme temperatures (for example the number of days over 35°C)
- lower average rainfall
- more frequent very high and extreme fire danger days (DSE, 2008).

The degree of climate change experienced, and the timeframe over which these changes occur, will be significantly influenced by global greenhouse gas emissions.

2.3.1 Greenhouse gas emission scenarios

The IPCC uses a range of GHG emission scenarios, which each provide a different estimate of the future trajectory of GHG emissions. Each scenario has been built based on a range of different demographic, economic and technological assumptions. For this study, GHG emission scenarios from the 'A1' family have been adopted (refer to Box 1 which represent a 'high emissions' future). This set of scenarios assumes a future of rapid economic growth, a global population that peaks in the middle of the 21st century, and the rapid introduction of new technologies.

Selection of these scenarios for this study therefore ensures that a cautious, conservative approach has been taken with respect to climate change projections. However, current global GHG emissions are tracking in line with this 'high emissions' future. Choosing a set of scenarios which represent a lower emissions future (such as the 'B1' family) would be unduly optimistic (Rahmstorf et al, 2007).

The following specific scenarios were used for this study:

- **The A1FI scenario** describes a future with the highest concentrations of GHGs, and therefore the greatest climate change, of the IPCC's emission scenarios.

- **The A1B scenario** describes a lower emissions future than the A1FI scenario, particularly in the latter half of the 21st century.

Box 1: Emission Scenarios

Emission scenarios are estimates of the future quantity of greenhouse gases that may be released into the atmosphere. These are based on assumptions about future demographic changes, and the implementation and efficiency of energy policies.

The Intergovernmental Panel on Climate Change (IPCC) developed a Special Report on Emission Scenarios (SRES) which is used in climate models. To reflect the latest rapid changes in societies since 2000, new emission scenarios are currently under development and are expected for release in 2013.

The IPCC emission scenarios are divided into four families: A1, A2, B1 and B2. A description of each scenario is provided in Table 1. Potential future global temperature changes associated with each of the two scenarios that have been modelled are presented in Figure 4, for low, medium and high rates of global warming.

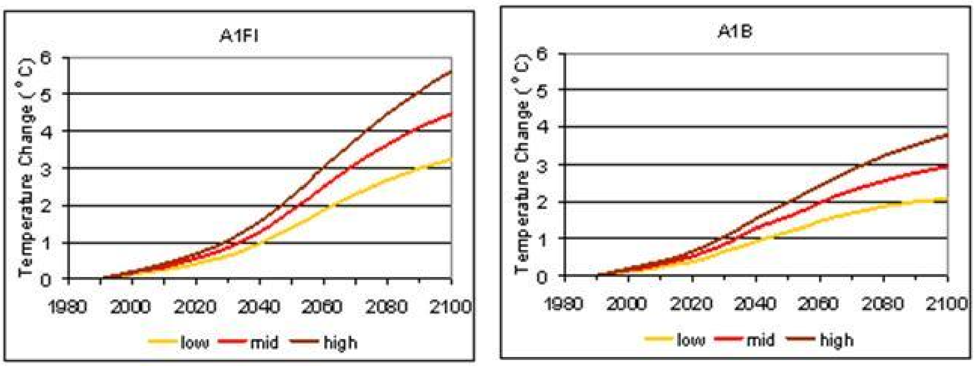
Table 1 SRES Scenarios (Nakićenović & Swart, 2000)

<table>
<tr><th>SRES Scenario</th><th colspan="2">Description</th></tr>
<tr><td>A1FI</td><td rowspan="3">Rapid economic growth, a global population that peaks mid 21st century and rapid introduction of new technologies</td><td>Intensive reliance on fossil fuel energy resources</td></tr>
<tr><td>A1T</td><td>Increased reliance on non-fossil fuel energy resources</td></tr>
<tr><td>A1B</td><td>Balance across all energy sources</td></tr>
<tr><td>A2</td><td colspan="2">Very heterogeneous world with high population growth, slow economic development and slow technological change</td></tr>
<tr><td>B1</td><td colspan="2">Convergent world, same global population as A1 but with more rapid changes in economic structures toward a service and information economy</td></tr>
<tr><td>B2</td><td colspan="2">Intermediate population and economic growth, emphasis on development of solutions to economic, social and environmental sustainability</td></tr>
</table>

The modelled GHG emission scenarios suggest the following potential future global temperature changes:

- a 5.5°C increase in global average temperatures by 2100, compared with 1990 levels, for A1FI
- a 2°C increase in global average temperatures by 2100, compared with 1990 levels, for A1B.

Figure 4 Global-average temperature change for low (yellow), mid (red) and high (brown) rate of global warming for the two SRES emission scenarios used in this study (Source: SRES 2000 in CSIRO 2010).



2.3.1 Global Climate Models

Twenty-three different Global Climate Models (GCMs) have been developed by researchers, to project the likely influence of GHG scenarios on the future climate. These GCMs use Atmospheric and Oceanic Global Circulation Models (AGCMs and OGCMs), in addition to other modelling inputs, to develop these climate change projections, and improve our understanding of climatology processes.

AGCMs and OGCMs rely on mathematical models of atmospheric and oceanic circulation to project changes in climate variables (CSIRO, 2011). Although the results from individual climate models can differ significantly, each one produces a plausible future climate for a given GHG emissions scenario. Typically, projections are created for individual climate variables such as minimum and maximum temperatures, for selected years and emission scenarios.

For the purposes of this study, we needed to identify which GCMs would be most relevant and appropriate. This task was done in consultation with CSIRO, in consideration of access to existing GCM outputs, format required for our study. Based on this process, all but four models were excluded. The following GCMs were used for the purposes of this study:

- Cccma_cgcm3_1_t47 (developed by Canadian Centre for Climate Modelling and Analysis)
- CSIRO-Mk3.0 (developed by CSIRO)
- CSIRO-Mk3.5 (developed by CSIRO)
- MIROC3.2(medres) (developed by the Center for Climate System Research at The University of Tokyo, the Japanese National Institute for Environmental Studies, and the Frontier Research Center for Global Change.

These models sample projected changes in temperature that cover most of the range of possibilities from 23 climate models. The Cccma_cgcm3_1_t47 was selected for use in this assessment.

2.3.2 **Projections of future climate change (temperature)**

The projection timeframes assessed for this study were:

- Now (based on the average observed conditions between 1971 and 2000),
- 2030 for A1B, and
- 2050 for A1B and A1FI.

The A1B and A1FI scenarios are essentially the same at 2030, hence only A1B is used for this time period.

Beyond 2050 was also considered as the impacts of climate change on UHI will increase significantly in the longer term. Table 2 summarises projections for high temperature days for 2030, 2050 and 2070 in Melbourne. The uncertainty of these projections increases as the projected period increases.

Table 2 Number of temperature threshold events per year for different climate scenarios without UHI

Temperature thresholds		Mean number of events per year					
		1971 - 2000	2030	2050		2070	
			A1B	A1B	A1FI	A1B	A1FI
Single days per year	30ºC	30.3	36.7	42.9	45.1	48.4	57.2
	35ºC	9.5	13	16.6	18.2	20.1	25.9
	40ºC	0.0	2.3	3.8	4.4	5.3	7.8
Three consecutive days per year	30ºC	3.4	4.8	5.6	6.1	6.9	9.1
	35ºC	0.7	1.1	1.6	1.7	1.9	2.8
	40ºC	0.0	0.0	0.1	0.2	0.2	0.5

2.4 Impacts of increased population

As a city of nearly 100,000 inhabitants and over 460,000 people in employment[1], Melbourne is a densely built up area. There is also a correlation between the size of the population of a city and the magnitude of the urban heat island effect. Torok et al (2001) present an equation that links population with the relative UHI effect, which is given by:

$$\Delta T_{u-r(max)} = 1.42 \log(POP) - 2.02$$

Where $\Delta T_{u-r(max)}$ is the maximum urban-rural temperature difference and *POP* is the relative population. This equation is based on Metropolitan Melbourne, and so projection of the population increase for the wider area is used to identify the potential increase in UHI.

Figure 5 Projected increase in UHI intensity based on the increasing population of Metropolitan Melbourne

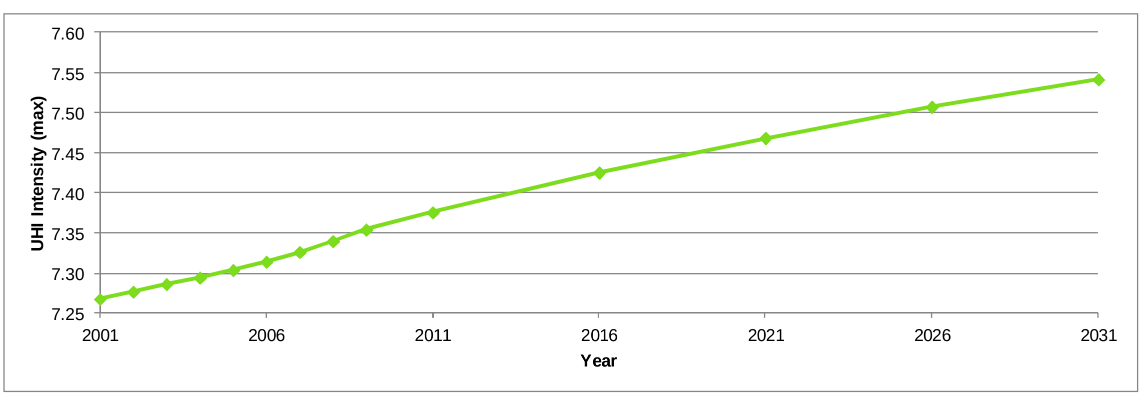


Figure 5 shows that the maximum urban heat island intensity, that is, the maximum difference between non-CBD and CBD temperatures throughout the whole year across Melbourne is likely to be less than 0.2°C. Due to the

[1] Based on 2011 figures: City Research 2011

magnitude of this increase and the uncertainty involved in future projections for both population and weather data, this impact has been deemed to be insignificant for this analysis.

2.5 Implications of Urban Development

The expected increase in population and visitors to the City of Melbourne will continue to drive growth and change in the urban form. The City of Melbourne's Municipal Strategic Statement has established a framework for urban development as outlined in Figure 1. The key directions in the new Municipal Strategic Statement (2012) are:

- planning for long-term growth in identified areas
- a well-connected and accessible city
- new developments to complement public places and spaces
- creating an 'eco-city'
- supporting a vibrant diverse and complementary mix of uses.

City of Melbourne is one of the most compact, dense parts of the metropolitan area and this style urban form is a driver for UHI heat island effect. Determining the likely future urban form is difficult with respect to the implications for urban heat island effect. The relationship between population growth and increase in density of urban form is discussed above. The style of the urban form developed is likely to influence the degree of impact on the UHI effect.

Development which integrates green spaces along with designs to reduce excess heat production from human activity (i.e. air conditioning, vehicle exhausts) is likely to reduce the UHI effect. However consolidation of development and activity in the future growth areas likely to increase localised UHI effects due the increases in thermal mass and heat absorbing materials (i.e. concrete and metals). The uncertainty regarding the changing urban form and its implications for UHI is too great to estimate due to these opposing forces.

Increased urban development will not only increase the resident population of the City, but will also likely increase the number of people employed in the city. The exposure to heat effects therefore tends to increase with development.

3.0 Temperature Projections and the UHI Effect

3.1 Introduction

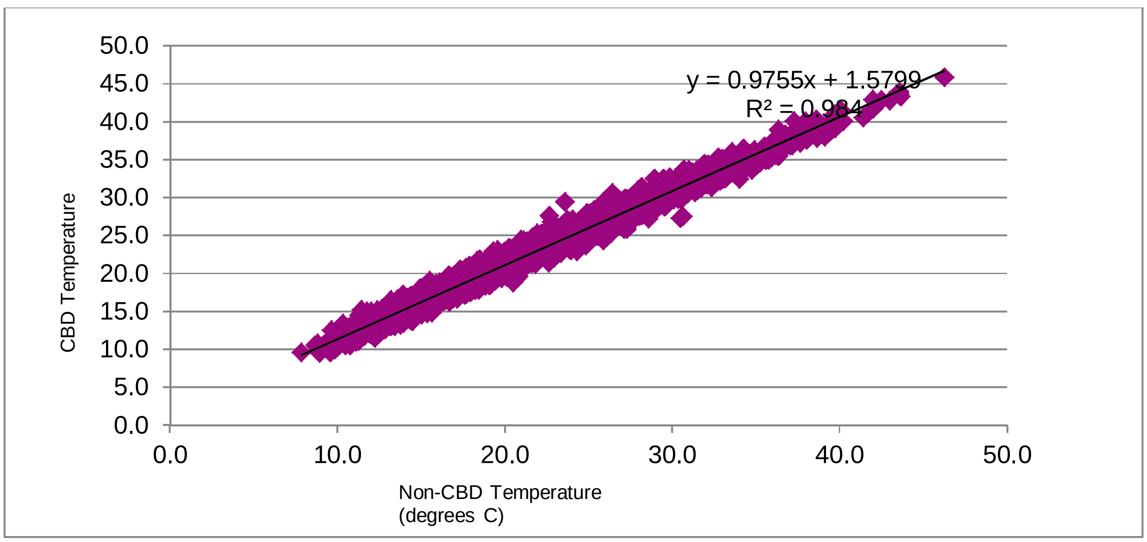
An Urban Heat Island will exist to an extent whenever an area contains more heat-absorbing materials than surrounding areas. UHIs therefore exist, to lesser or greater extents, across the whole landscape. This study focuses on the UHI that exists in the City of Melbourne, largely due to the high concentration of heat-absorbing materials within the CBD.

The analysis here discusses how the temperature varies between the CBD and non-CBD areas during peak heat events, i.e. single hot days and heatwave events, where temperatures exceed a particular threshold for three or more consecutive days. Analysis is based on weather data measured at Melbourne Regional Office in the CBD, and in three non-CBD areas; Melbourne Airport, Moorabbin Airport and Laverton RAAF base. Hourly temperature data has been obtained for each weather station from the Bureau of Meteorology for all available time periods. To provide consistent analysis, data sets are taken from 28 July 1998 up to 15 September 2011 – a period when all four weather stations provided consistently full data measurements for temperature.

3.2 Determining the UHI effect

The difference in daytime temperature due to the UHI is shown by first considering the daily peak temperatures in non-CBD areas and comparing them to the peak daily temperatures measured in the CBD. Peak daily within and outside the CBD have temperatures have been plotted against one another to determine the relationship between them and, and hence the UHI effect (see Figure 6).

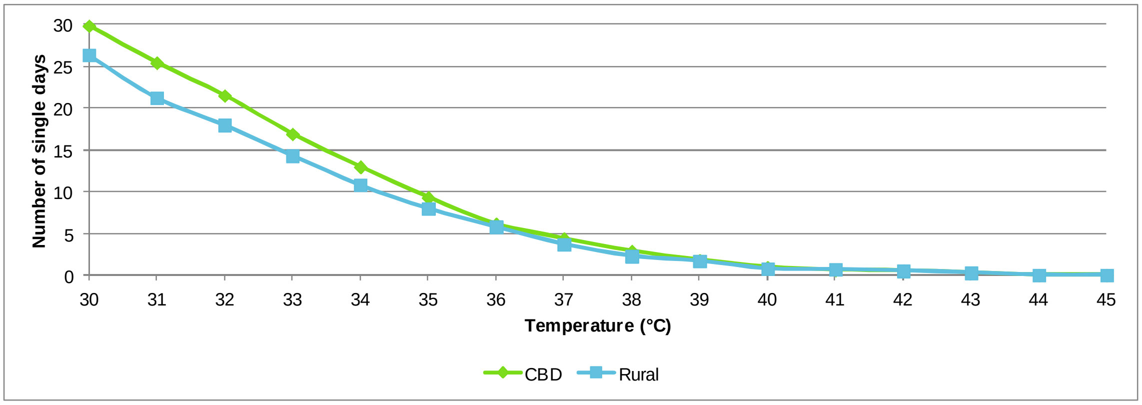
Figure 6 Relationship between CBD and non-CBD temperatures (1998-2011)



The relationship between the two is strongly linear and, interestingly, shows that the UHI effect decreases with increasing temperature. At 30 degrees C in non-CBD areas, CBD temperature is found to be 30.8 degrees – a UHI effect of 0.8 degrees. At 40 degrees C in non-CBD areas, CBD temperature is 40.5 degrees – a UHI effect of 0.5 degrees. This is likely to be caused during hot days by the thermal storage within hard surfaces of the CBD emitting less heat as the temperature differential between the surface and the air is less. There are also less occurrences of higher temperatures within the data set, and hence there is greater uncertainty in estimating the UHI effects in the upper temperature range. This is explored further for consecutive hot days in Section 3.2.1.

The number of days that sit above each temperature threshold were then counted for both CBD and non-CBD areas. Figure 7 shows the average number of single days above different temperature thresholds that have been observed over the last 12 years.

Figure 7 Number of days exceeding 30°C and above between 1999 and 2010

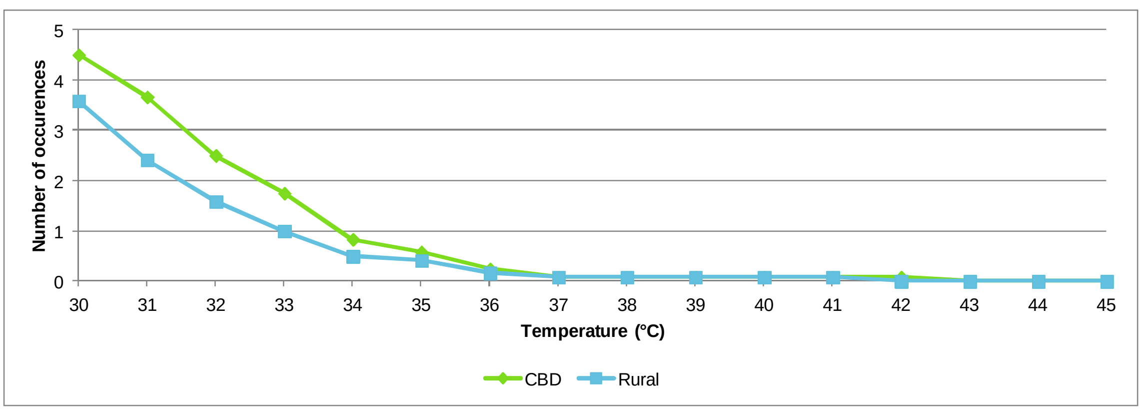


Historical data shows that non-CBD areas experience around 26 days above 30°C on average. The urban heat island effect increases the number of occurrences to almost 30 days – just over a 10% increase. As temperatures increase, the number of days where the CBD is hotter than the surrounding decreases. At 42°C and above, there is little evidence to show that there are more days with higher peak temperature inside the CBD than outside.

3.2.1 Consecutive Hot Days

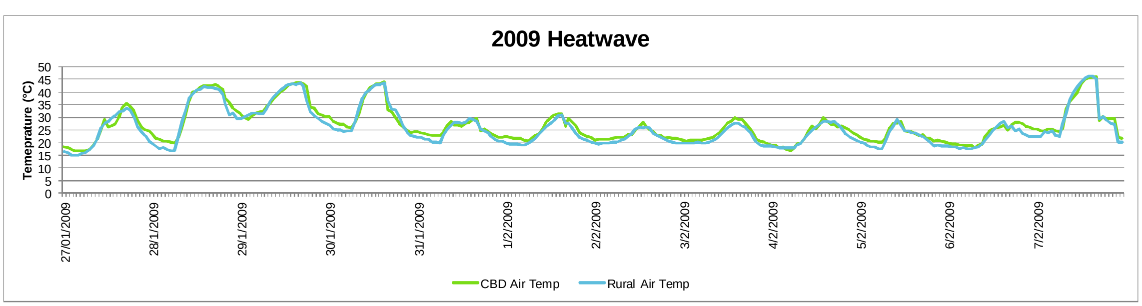
Projected data from climate change modelling obtained from CSIRO also considers the number of occurrences where the peak daily temperature exceeds certain values for three or more days. To assess the relative impact of the urban heat island, all consecutive days above a range of temperature thresholds are identified for both non-CBD and CBD air temperatures with the average number of occurrences per year shown in Figure 8.

Figure 8 Number of occurrences of three or more consecutive hot days above a range of temperature thresholds



Again, the largest difference in number of occurrences is seen at the lower end of the peak temperature scale. As peak daily temperatures rise above 40°C, very little difference between non-CBD and CBD temperatures is apparent. To understand this in more detail, a number of recent heatwave events are considered by looking at the change in hourly temperatures between the CBD and temperatures in the surrounding non-CBD areas.

Figure 9 Hourly temperatures for CBD and non-CBD areas during the 2009 heatwave



The last and most significant heatwave in Melbourne occurred in the summer of 2009. Hourly temperature readings shown in Figure 9 display the minimal effect of the urban heat island at high day time temperatures, however there is a significant difference in temperature during the night, with non-CBD areas experiencing temperatures up to 5°C lower than those observed in the CBD. Similar patterns can be seen for heat wave events in the summers of 2000, 2006 and 2007 (Figure 10, Figure 11 and Figure 12, respectively) where at the highest temperatures, little difference between the CBD and non-CBD air temperatures was measured. Again, the largest impact of the urban heat island effect is overnight. Despite this, the *impacts* of this effect at night tends to be lower than during the day because overall temperatures at night are generally below the thresholds at which impacts occur. This is explored further in later sections, however an exception to this that should be noted is that higher overnight temperatures during periods of hot weather do tend to impact on biological systems by prolonging the stress of heat – the UHI robs them of an overnight recovery period.

As the data provided in the CSIRO projections only considers peak daily temperature estimates, this over night non-CBD cooling is not captured.

Figure 10 Hourly temperatures for CBD and non-CBD areas during the 2000 heatwave

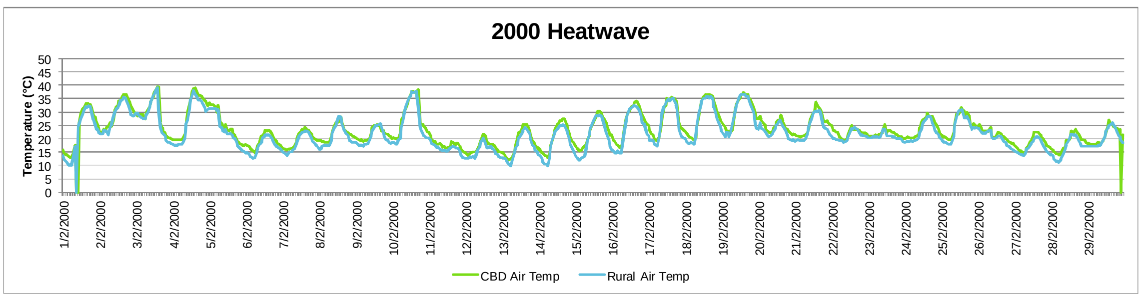


Figure 11 Hourly temperatures for CBD and non-CBD areas during the 2006 heatwave

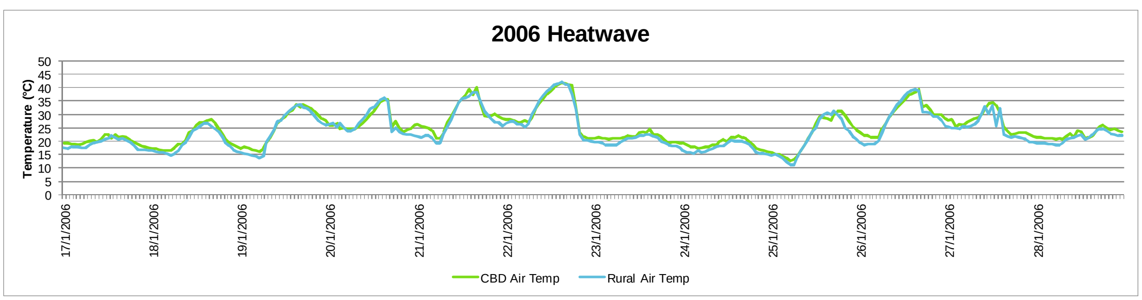
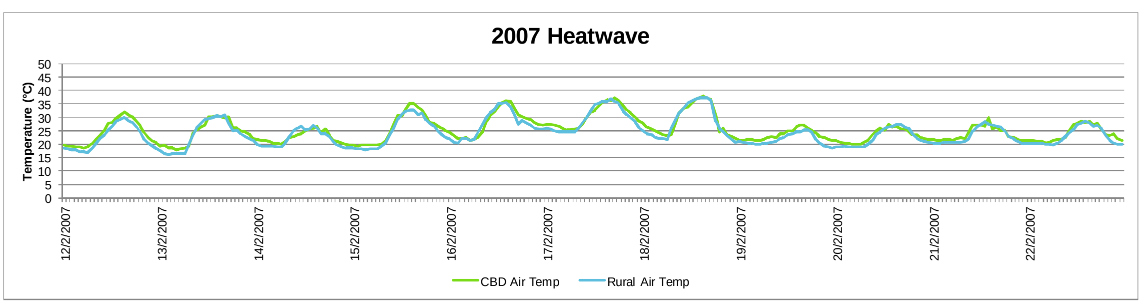


Figure 12 Hourly temperatures for CBD and non-CBD areas during the 2007 heatwave

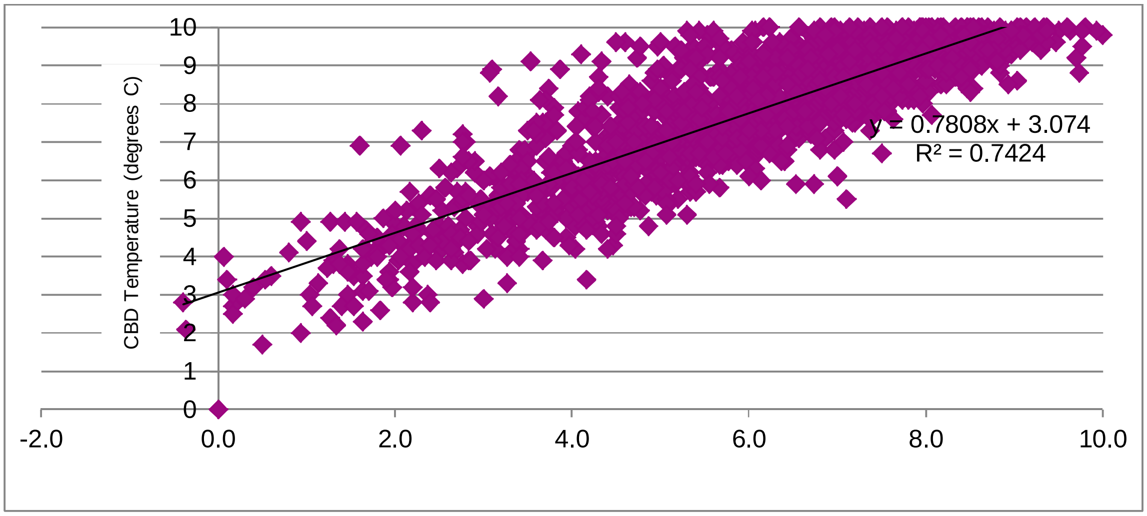


The climate change projection data is provided in single degree temperature bands between 30°C and 45°C for single day occurrences and heat wave events of three days or more. Based on the increase number of occurrences observed in the CBD compared to non-CBD areas, the projection data has been adapted to show the potential impact of the UHI effect when combined with climate change.

3.3 The UHI in winter

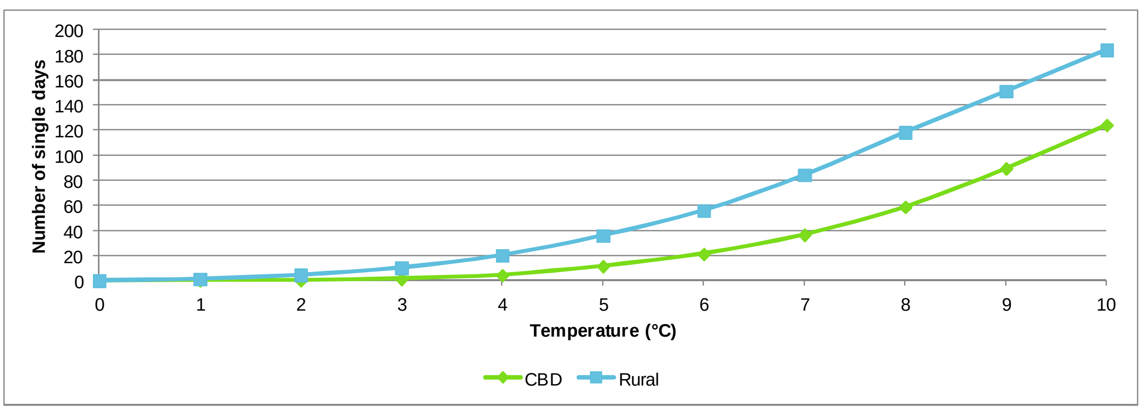
During winter, CBD temperatures are generally higher than those experienced in non-CBD areas. Presented in Figure 13 is a chart showing the relationship between CBD and non-CBD peak temperatures. Although the relationship is less strong than for the higher temperature examined earlier, it once again shows a decreasing UHI effect with increasing temperature. As a result the UHI effect is greater at these lower temperature than at the higher temperatures above 30 degrees. At 5 degrees C in non-CBD areas, the CBD temperature is approximately 7 degrees – a UHI effect of 2 degrees. This has some interesting implications for energy use, as is revealed later in the analysis.

Figure 13 Relationship between CBD and non-CBD areas at temperatures below 10 degrees (1999-2010)



In the reverse to hot weather, at lower peak temperatures the CBD and non-CBD experience a similar number of occurrences. Again this is likely to be due to the limited data available at low temperatures. The climate projections for cold weather spells has been adapted to include the effects of the UHI in a similar process as that undertaken for hot weather

Figure 14 Number of days at 10°C and below between 1999 and 2010



4.0 Impacts of Heat and the UHI effect on the Community

4.1 Introduction

Hot weather results in a wide range of impacts on the community and its assets. Health, human behaviour, infrastructure and the natural environment are all affected by high daily temperatures. The Urban Heat Island (UHI) effect exacerbates these impacts by increasing not only day-time temperatures within urban areas, but also night-time temperatures, and sequences of days and nights with high temperatures.

The focus of the discussion in this chapter is on the impacts of hot weather on community assets and values, and what sort of relationship exists between temperatures and impacts on these items. Since UHI tend to be an exacerbation of these impacts, by first understanding the relationship between hot weather and impacts, the additional impact due to the UHI can be assessed.

4.1.1 The Southern Australian heatwave of 2009

From the 27th of January to the 8th of February in 2009, southern Australia experienced a heatwave that had a severity that was unprecedented in recent history in Australia. Not surprisingly, this caused a wide-range of impacts on the community that were serious enough to provoke a range of investigations and studies to better enable future planning. The data and information arising out of these investigations has proven to be valuable to this study.

Particularly useful in understanding the impacts on the community of the 2009 heatwave is a study produced by a combination of academic institutes as an initiative under the National Climate Change Adaptation Research Facility (NCCARF). The study, entitled “Impacts and adaptation response of infrastructure and communities to heatwaves: the southern Australian experience of 2009”, has been the source of many of the understandings of how high temperatures impact on the Melbourne community and it assets.

4.2 Health

The impacts of hot weather on health are profound, particularly amongst more vulnerable members of the community such as the elderly, and the correlation between temperatures and health impacts is strong beyond a threshold temperature.

The increased vulnerability among the elderly is attributable to a combination of impaired physiological response to heat, and a higher prevalence of chronic diseases involving cardiovascular, respirator, renal, and endocrine systems (Department of Human Services, 2010). However, groups lacking the capacity to avoid or reduce exposure to the heat hazard are also among the vulnerable. The heatwave in 2009 led to a sharp increase in heat-related illnesses amongst the most vulnerable groups (NCCARF, 2010).

Sequences of high temperature days, which tend to occur along with higher overnight temperatures, have a greater impact on health due to a lack of relief and recovery time. Loughnan et al (2010) found a significant relationship between hot temperatures and hospital admissions of patients suffering Acute Myocardial Infarctions (heart attacks) over the Melbourne Metropolitan area. The study found the following:

- On average, a 10.8% increase in AMI admissions on days exceeding the threshold temperature of 30 ºC
- On average, a 37.7% increase in AMI admission during short episodes of heat (when the 2-day average temperature is greater than 27 ºC)
- AMI increases during hot weather were only identified in the most socio-economically disadvantaged and least disadvantaged areas
- Districts with higher AMI admission rates during hot weather also had larger proportion of older residents
- Age appears to be a better explanation than socioeconomic status for AMI admission during both single hot days and short-episodes of hot weather.

The Department of Human Services undertook an analysis of the impacts and responses to the 2009 heatwave. The analysis assessed ambulance attendances, emergency department presentations, and mortalities, in the Melbourne Metropolitan area for the week of the heatwave between the 26th of January and the 1st of February. More of this information is presented in the economic assessment in Section 5.3. The study found the following:

- Ambulance attendances to heat-related conditions during the 2009 heatwave increased by 499 cases, from 15 in the same period during the previous year – a 34-fold increase.
  - Of these, 61% were aged 75 years or older
  - Of all attendances, 80% of cases were transported to hospital
- Emergency Department presentations for heat related conditions (heat stroke, heat syncope, and dehydration) increased to 714 from an expected 85 (an 840% increase) of this, 325 (46%) were in people 75 years or older.
- Mortalities were 62% greater than expected – an additional 374 deaths above what was expected for the time period.
- Mortalities that were designated reportable deaths[2] collected by the State Coroner's Office and showed an increase of 78 deaths (77%) for the week of the heatwave compared with the same time period in 2008, which included more than triple the deaths expected for 75 year olds and above, and more than double the deaths expected for the 65 – 74 years age group. No statistically significant difference in reportable deaths was found below this age group.

International research findings are consistent in the view that the elderly (>75 years old) are the highest group at risk during heatwaves to experience (Navigant, 2009). In addition, Ostro et al (2009) found that for the Californian heatwave of 2006 , daily mortality rate increased by 9% per 10 ºF.

[2] Reportable deaths to the Coroner include those where the identity of the deceased is unknown, or the death was either violent, unnatural, suspicious, or occurred in custody or care.

4.3 Transport

Hot weather can affect transport systems in a variety of ways. Trains and trams overheat, rails buckle, air-conditioning units are pushed beyond capacity, buses and cars break down. The effects of heat on different transport systems within the City of Melbourne are examined below.

4.3.1 Trains

The Melbourne Metropolitan rail network has experienced significant impacts on service in recent times. During the 2009 heatwave more than 750 services were cancelled, due to a number of reasons including:

- Buckled train lines.
- Failure of air-conditioning systems.
- Electrical faults/power outages.

In their assessment of the 2009 heatwave, NCCARF found that during the heatwave there were 29 instances of rail lines buckling that either slowed or disrupted services. Failure of air-conditioning systems also caused a significant number of cancellations. More than half the fleet (331 trains) were the older Comeng trains that contain air-conditioning units that are not designed to operate above 34.5 degrees. The greatest number of cancellations occurred on the third day of the heatwave, with electrical power failures becoming an additional cause of train cancellations.

Although probably the most severe, the 2009 heatwave was not the only time that heat has impacted on the rail system. AECOM undertook a study in 2011 into the impacts of hot weather on Melbourne's urban commuter rail system as part of an assessment of adaptation options to climate change for the rail network. The study investigated the average Passenger Weight Delay Minutes (PWDM – total time delayed aggregated across total passengers affected) attributable to hot days, and sequences of hot days. The study found a significant relationship between PWDM and temperatures, with significantly greater impacts during consecutive hot days. These delays are largely a consequence of air-conditioner failures, although other factors are recognised as contributors. These findings are examined further in the assessment of economic impacts in Section 5.4.

4.3.2 Trams

Melbourne tram tracks also buckled during the 2009 heatwave at Port Melbourne, Airport West, and Royal Park (NCCARF, 2010). However these occurred predominately on the first day, with remediation measures being sufficient to prevent recurrences on subsequent days. Additionally, in contrast to trains during that period, only a few trams services were cancelled. It was still possible to operate on buckled tracks, although speeds were drastically reduced resulting in delays for passengers, but there were minimal cancellations. NCCARF note that despite the heatwave, Yarra Trams met all performance targets for the month.

About half of the trams operable during the heatwave had air-conditioning. The air-conditioning systems were relatively new and were able to cope with the hot conditions – no failures were reported (NCCARF, 2010). The passengers on the remaining trams were forced to endure the high temperatures and may have been some of those accounted for in the description of health impacts in Section 4.2.

4.3.3 Vehicles

Road vehicles are susceptible to hot weather conditions, particular older models or those already in a deteriorated condition. In regard to cars, there is little information with which to quantify a relationship between car breakdowns and temperatures, however anecdotal information suggests an increase in breakdowns with higher temperatures.

NCCARF (2010) report that the bus services in Melbourne were not significantly affected during the 2009 heatwave, but noted that air conditioners struggled at temperatures above 35 degrees C. Despite this, unlike the train service, bus services continued to operate and hence there were no significant impacts on commuter travel times. The bus service did provide a backup service for the trains and experienced shortages during this time.

4.3.4 Roads

The bitumen component of roads has a tendency to become soft and sticky during hot weather conditions, which can have consequential effects for traffic movement if the road deteriorates. NCCARF (2010) found that, although some of these impacts occurred across Metropolitan Melbourne, roads within the boundary of the City of Melbourne are constructed with a higher degree of durability, and consequently did not suffer any heatwave impacts.

4.3.5 Seaports

The Port of Melbourne is Australia's most significant maritime port for general and container cargo.

NCCARF (2010) report that under the current Enterprise Agreement for operators at the Port of Melbourne, workers can take a 15 minute break every hour if temperatures exceed 35 degrees C, and can stop work altogether if the temperature exceeds 38 degrees C, until the temperature cools.

NCCARF report that there is a loss of productivity each summer due to heat, although this loss is not quantified beyond a report of 72 crane hours lost in 2009 and 49.5 crane hours lost in 2010. NCCARF found that above 40 degrees C, mechanical problems became more prevalent. However, this information is insufficient to assess the economic impacts under projected temperatures.

4.4 Energy

The UHI effect can have a significant impact on the level and pattern of energy demanded as it makes the city hotter in summer and warmer in winter. It is therefore reasonable to expect that, because of the UHI effect, energy demand in the City of Melbourne would increase in summer for cooling and a reduction in energy needed for warming in winter. Cooling and heating are typically energy intensive processes and can lead to high energy cost during extreme weather conditions.

Cooling in Australia is typically achieved with reverse cycle or evaporative air conditioners, with the former being significantly more energy demanding and more effective than the latter. Gas heating is common for both residential and commercial buildings, although significant spot heating is achieved with highly energy intensive electrical heaters.

The need to control indoor temperature typically does not arise when external temperatures are within comfortable levels. The definition of a comfortable temperature ranges varies from person to person. Consequently, energy consumption profiles are also variable.

Citipower, the electricity distribution for the City of Melbourne, reports that, for every incremental degree of average daily temperature that is above 20ºC, its network load is expected to increase by 0.228GWh, driven by cooling requirements of its customers. In cooler temperatures, for every degree of average daily temperature below 16ºC, its network load is expected to increase by 0.283GWh.

Since the City of Melbourne consumes approximately 60% of the electricity generated by Citipower, for every degree beyond the threshold temperatures the UHI effect adds to the temperature of the City of Melbourne, it is likely to induce 0.137GWh increase in electricity demand in summer and 0.17Gwh reduction in electricity demand in winter.

The level of peak energy demand can also be affected by increased temperatures. Peak energy demand refers to the maximum level of energy consumed by the users at any one time, and is a primary determinant in the scale and type of infrastructure that is required to supply energy requirements. The increase in the level of peak demand can have serious economic implications for the energy supplier in terms of their need to upgrade or build additional infrastructure to expand the network capacity. Citipower estimates that its network sensitivity for peak demand is 36.6 MVA (Mega-volt-ampere) for every 1ºC increase in summer daily temperature. Based on this estimate and assuming 60% share of Citipower's maximum demand is driven by the City of Melbourne users, the UHI effect can therefore be expected to increase the maximum demand in the City by approximately 22.0 MVA for every Celsius degree it adds to the maximum temperature in summer.

Although future infrastructure upgrades are factored into today's prices for electricity and include allowances for increases in future peak load (see Appendix C), unexpected increases in demand that might occur with unforseen temperature impacts would require these upgrades to occur sooner than expected. Assessing this cost of earlier upgrade requires an understanding of the costs and timing of future augmentations and involves an analysis that is beyond the scope of this project.

Increased energy demand can also mean more frequent occurrences of system faults due to network overload. In Table 3, CitiPower provides an estimate of the relationship between hot weather temperature and its impact on its network performance in terms of SAIDI[3] and the incidence number of equipment failures. Note that The System

[3] The System Average Interruption Duration Index (SAIDI)[1] is commonly used as a reliability indicator by electric power utilities. SAIDI is the average outage duration for each customer served, and is calculated as:

$$\text{SAIDI} = \frac{\text{sum of all customers intteruption durations}}{\textit{Total number of customers served}}$$

Average Interruption Duration Index (SAIDI)[1] is commonly used as a reliability indicator by electric power utilities. SAIDI is the average outage duration for each customer served, and is calculated as ratio of the sum of customer interruption durations over the total number of customers served.

Table 3 Network response of the CitiPower network to hot days

Maximum daily temperature range per year	Daily average High Voltage SAIDI (min)	Daily average Low Voltage SAIDI (min)	Daily average SAIDI (min)	Daily average number of high voltage faults	Daily average number of Low voltage faults
30 – 35 ºC	0.06	0.001	0.06	0.3	1.9
35 – 40 ºC	0.26	0.024	0.29	1.3	7.5
>40 ºC	0.14	0.055	0.20	0.7	8.4

Source: CitiPower 2009

4.5 Anti-Social behaviour

Anti-social behaviour is defined in this study as human actions, whether by individual or group, that are harmful to other members of the society. These harmful actions, mostly recognised as being in violation of the law, can be highly costly for the society within which they take place. Direct economic costs as a result of the occurrences of anti-social behaviour can include the financial loss due to damages afflicted on people and property, public funding of crime prevention and policing, as well as for maintaining the justice system such as courts and correctional facilities. The personal suffering of the victims is also an economic cost, although for the most part it is not monetised.

The study of human behaviour is a highly complex and sophisticated subject. At an individual level, it is the domain of psychologists and medical psychiatrists who examine and theorise the influences of both internal and external factors on the human psychic and ultimately their manifestation through human behaviours. At a society level, statistical studies have led the discussion on the relationship between external factors and the level of various types of crime and anti-social behaviours. Increased environmental temperature, a key outcome of the UHI effect, is found to have a mixed degree of impacts on the different types of criminal behaviours.

Research in to temperature-related behaviour effects within Australian is found to be extremely limited. There is considerably more literature available from international sources, especially in the United States.

The key insight from the US research on the effect of temperature on the level of crime in society can be summarised as follows:

1) Weather temperature can increase the level of crime in society
2) The impact of temperature on the level of criminal activity varies across crime categories
3) The impact of the temperature on crime can be inconclusive in some cases potentially caused by the fact that key explanatory variables have not been accounted for in the specification of the statistical models

Cohn (1990) reviewed a large body of literatures on the influence of hot weather on crime in the United States. A summary of the various types of crime is provided in Table 4. Hot weather in defined as days with mean temperature higher than 90ºF (32.2ºC).

Table 4 The influence of hot weather and crime level US

Crime type	Findings of US based research
Collective crime (e.g. riots)	A positive linear relationship exists between the probability of collective crime and temperature
Assault	A positive linear relationship exists between the probability of assault crimes and temperature
Homicide	Inconclusive, strongly contradictory findings exist
Rape	Possible linear relationship, some studies find positive relationship whereas others show no clear relationship exists.
Robbery	No relationship is found by the available studies

Crime type	Findings of US based research
Domestic violence	A positive linear relationship exists between the probability of domestic violence crimes and temperature
Non-aggressive crimes	Positive linear relationship only exists between burglary and hot weather, and not for larceny or motor vehicle theft

Collective crime, assault, domestic violence and burglary are the types of anti-social behaviours that are found to be significantly and positively related to temperature in the United States. More recent studies show that hot weather is highly correlated with violent crimes such as assault and homicides. It is found that that, on hot days (days with maximum temperature exceeding 90ºF or 32.2ºC) for every 1ºF increase in temperature, the number of violent crimes (murders and assaults) is increased by 3.68 per 100,000 people. (Anderson, Bushman & Groom, 1997)

Finally, in the Australian context, Auliciems & DiBartolo (1995) found that, during all seasons, as the maximum air temperature increases so does the number of police calls for domestic violence incidences in Brisbane. Based on a threshold temperature of 25ºC, the best model in the study suggests that, on a weekly basis, as the maximum temperature increases by 1ºC, the weekly number of police calls related to domestic violence increased by 0.549.

4.6 Trees and Animals

Trees

The City of Melbourne is home to an array of parks, reserves, gardens and boulevards. Contained within these environments are approximately 80,000 trees, three-quarters of which are on public land and managed by the City - although there is considerable uncertainty around the number of trees on private property. Public trees comprise more than 388 different species across a range of age groups (City of Melbourne, 2012). Canopy cover in the public realm is approximately 22% - City of Melbourne plans to double this over the next two decades.

Trees cool the air by the process of evapotranspiration. Soil retains water for longer periods of time than hard surfaces therefore evapotranspiration can be extended in duration where there is greater soil volume. The canopy also has an effect by shading hard surfaces that would otherwise absorb direct sunlight. Through these mechanisms trees provide a cooling effect that counters heat, and Urban Heat Island, impacts. To maximise these benefits, it is essential to maintain adequate soil moisture for trees during periods of high temperature. If soil moisture becomes severely limited, not only do trees stop transpiring when the cooling benefits are needed most, but their health can be negatively affected by severe water and heat stress.

Initial studies by City of Melbourne show that temperature directly underneath the canopy by 0.7 - 6.8 degrees.

Hot weather affects tree species differentially, with native species tending to survive with less irrigation during hot, dry periods than their exotic counterparts. However, species that are highly adapted to survive hot, dry conditions tend to use less water, which means that their cooling benefits also tend to be less. Therefore, selecting species that maximise cooling benefits needs to be balanced with an ability to maintain adequate soil moisture for the selected species to survive. In general, the impacts of high temperatures on trees can be managed through additional irrigation. However there are temperature thresholds beyond which tree health will be negatively affected regardless of water availability.

Melbourne's recent period of drought from 1997 until 2010 resulted in reduced rainfall available for the City's trees and water restrictions that limited irrigation with reticulated potable sources. For some trees, extreme heat in 2009 coupled with severely limited soil moisture resulted in a decline in health of the City's trees and a reduced life expectancy.

A current return to decent rainfall and the increased availability of water as a result of supply augmentations, most notably the desalination plant and the many stormwater harvesting projects delivered by City of Melbourne, means that the likelihood of the City (and residents) being unable to provide adequate irrigation for trees in the future is diminished – at least over the medium-term (and albeit at higher costs). This means that the past decade's impacts on the City's trees are unlikely to be a useful guide to future impacts, and relationships between past water use and temperature cannot easily be revealed.

The relationship between water use and temperature was explored in Beech trees in a study by Strelcova et. al. (2002). A tree's water use is based on its transpiration rate, which is the rate at which water passes through the trees leaves via the stomata. In the aforementioned study, transpiration rates in trees were estimated by measuring the rate at which sap flows within the xylem. Transpiration rates show a strong linear relationship with temperature, with three relationships derived based on varying 'social positions' of the tree. This has been used as a proxy for the amount of water required by trees across different temperatures in the economic assessment in Section 5.7.

Animals

The City's native fauna are affected by increased temperatures both directly, through heat-related health impacts, and indirectly through impacts to flora which are used as habitat and sources of food. Street trees have been identified as a driver of recent increases in the population of Grey headed flying foxes in Melbourne providing additional food resources (Kendal, 2011). Native birds often preferentially use native street tree species and may be driven out of the city if such habitat becomes unavailable or unsuitable, with consequential impacts on the amenity value of the urban environment.

The health of pets is likely to be affected in much the same way as human health. Reliable information on these impacts is not readily available, however, being reliant on owners for adequate shelter and water, and with no ability to express health problems, it is arguable that there is a greater potential for pets to suffer adverse impacts of hot weather.

4.7 Major Events

The City of Melbourne is renowned for its major events, many of which operate during the height of summer. From sporting events such as the Australian Open, the Grand Prix and Boxing Day Test, to cultural events such as Moomba and a plethora of music concerts and festivals, Melbourne's major events are a key attraction for tourism and a source of pride and enjoyment for residents of the city. A list of the major summer events that occur annually is presented in Table 5.

Table 5 Annual Major Events in Melbourne over Summer

Major Event	Description
Melbourne Boxing Day Test	International cricket match event held at the Melbourne Cricket Ground from December the 26th.
Carols by Candlelight	Christmas Eve charity held at the Sidney Myer Music Bowl in the King's Domain Park
New Year's Eve Celebrations	Fireworks and parties at various public locations around the city
Australian Open Tennis	International tennis competition – the first Grand Slam of the year at Melbourne Park.
Music Festivals	Summerdayze, Big Day Out

The potential impacts of hot weather on these events include:

- event cancellations;
- reduced attendances; and
- discomfort and adverse health impacts for attendees and performers.

Data and information to quantify the impacts of heat on these events are not readily available. There do not appear to be any records of cancellations due to heat of any of the major events listed in Table 5. There are no readily available analyses of heat impacts on attendances, and attendance information by date with which to conduct such an analysis is difficult to obtain.

4.8 Other Impacts

Impact on well-being

In addition to the physiological health impact described in Section 4.2, other potential impacts on the well-being of human beings affected by the UHI effect can include changes in income level (and consequently, standard of living), and mental health.

The negative relationship between rising average temperature and the level of national income measured in terms of Gross National Product (GNP) is suggested by the Garnaut 2008 Review, in which a 5ºC warming due to unmitigated climate change can lead to 0.2% reduction in GNP[4] from 2008 to 2010 and 1.3% reduction in GNP by 2030.

The impact of higher temperature on mental health is most evident once it exceeds comfortable levels. Although the tolerance level for hot weather varies from person to person and critically depends on the ability to access an air-conditioned environment, higher temperatures are likely to lead to heightened irritability and difficulty with sleeping at night. Mentally ill patients are particular at risk during heat-wave as discovered by Hansen et al (2008), who found that hospital admissions for mental and behaviour disorders are positively correlated with ambient temperature above a threshold temperature of 27 ºC.

However, the warmer environment created by the UHI effect can also potentially create positive impact on the well-being of the society. Research shows that travelling to warmer areas during winter has the benefit of improving mood, memory and cognitive function of the brain.[5] This finding can support the beneficial impact UHI effect can have on the well-being of Melbourne dwellers during winter periods.

Impact on demand for water and water infrastructure

In addition to increased urban irrigation requirements discussed earlier, UHI effect has the potential to affect water demand and have an impact on water infrastructure. Increases in average atmospheric temperature can accelerate the rate of evaporation and demand for cooling water for humans and machinery.

During the recent drought in Victoria, conservation efforts included a non-mandatory target for public consumption of 155L of potable water per person per day. On days with peak temperature greater than 30ºC, this target was regularly exceeded (RMIT, 2009).

Other water related impacts due to higher temperature include the faster evaporation from water reserves which can potentially cause drought concern if rainfall is limited, and the increased need for water to overcome bush fire hazards. These two impacts are assessed to be not particularly relevant for the City of Melbourne and therefore not considered in this report.

Impact on retail sales

The warmer ambient temperature created by the Urban Heat Island Effect can also have a potential impact on the sales performance of retail businesses located within the affected area.

In a US study on the effect of weather on retail sales, Starr-McCluer (2000) found that temperature does affect the shopping behaviour of the population, but this effect is only limited to the timing of the sales and not the overall quantity of goods sold.

Specifically, warm weather is likely to boost retail sales in a particular month or quarter; however this is always followed by another month or quarter of substantially lower than average sales volume, offsetting the sales growth in the previous period. The author provides a possible explanation by attributing the fact that temperature does change human behaviour but has limited impact on the consumers' budget constraint, and hence does not affect longer-term spending patterns.

Other impacts

There are other economic impacts that may have not been included in this study and these include: increased fuel costs associated with powering air-conditioners in vehicles, increased repair cost associated with vehicle break-down due to over-heating, increased administration cost associated with local governments handling heat induced complaints from local residents, increased revenue for businesses that sell products or services that are more desirable during hot weather (eg drinks, ice creams, public pools etc).

This report has focussed on the economic impacts that have received priority in research and have reasonable data with which to quantify impacts.

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[4] GNP is used instead of GDP by the Garnaut 2008 Review which argues is a better representation of welfare for Australians

[5] M. C. Keller, B. L. Fredrickson, O. Ybarra, S. Cote, K. Johnson, J. Mikels, A. Conway, T. Wager. A Warm Heart and a Clear Head: The Contingent Effects of Weather on Mood and Cognition. Psychological Science, 2005; 16 (9): 724 DOI: 10.1111/j.1467-9280.2005.01602.x

5.0 Economic Assessment of Impacts of Heatwaves and the UHI Effect

5.1 Introduction

The previous section discussed the range and types of impacts that hot weather conditions can pose. Where possible, the assessment has drawn on Melbourne-based studies. This sections aims to assess the economic impact of heatwaves and the Urban Heat Island effect.

To be clear, the economic impacts being measured here are:

- The impacts of heat;
- The impacts of heatwaves; and
- The contribution of the Urban Heat Island to the above impacts.

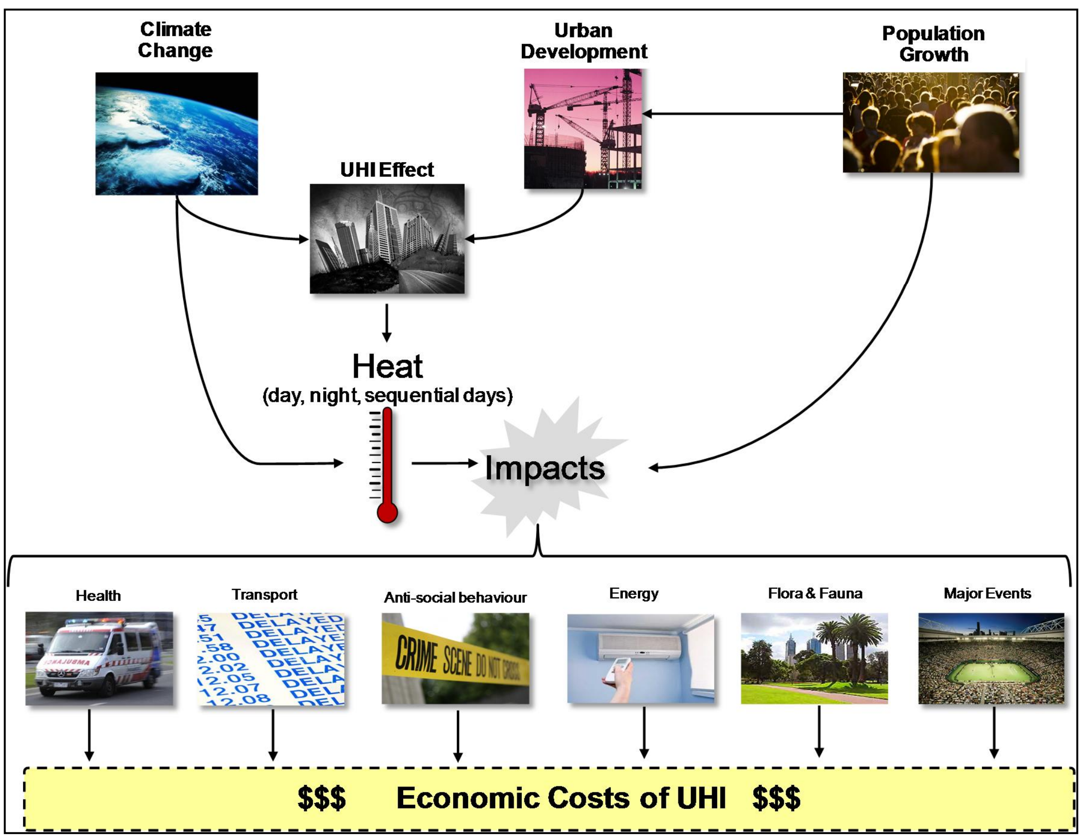
The assessment is focussed concerned on the direct impacts of heat within the study area – the City of Melbourne (see Figure 1) – but recognises that these localised heat impacts can produce economic impacts beyond the study area.

This section begins with a general overview of the methodology before a more detailed description and assessment of each of the impacts explored in the previous section. The results of this analysis are then summarised and discussed in Section 5.10, followed by a sensitivity analysis of some of the key input variables and assumptions. The outcomes of this analysis are then distilled in the recommendation and conclusions section that follows.

5.2 Overview of Methodology

An overview of the assessment methodology is presented in Figure 15.

Figure 15 Assessment methodology



The previous chapters have provided answers to the following questions, which relate to the top half of Figure 15:

- How do temperatures and sequences of high temperatures (heatwaves) relate to impacts on the Melbourne community?
- What impact does the Urban Heat Island Effect have on temperatures within the City of Melbourne?
- What impact does climate change, population growth, and urban development have on the UHI effect, and hence temperatures within the city?

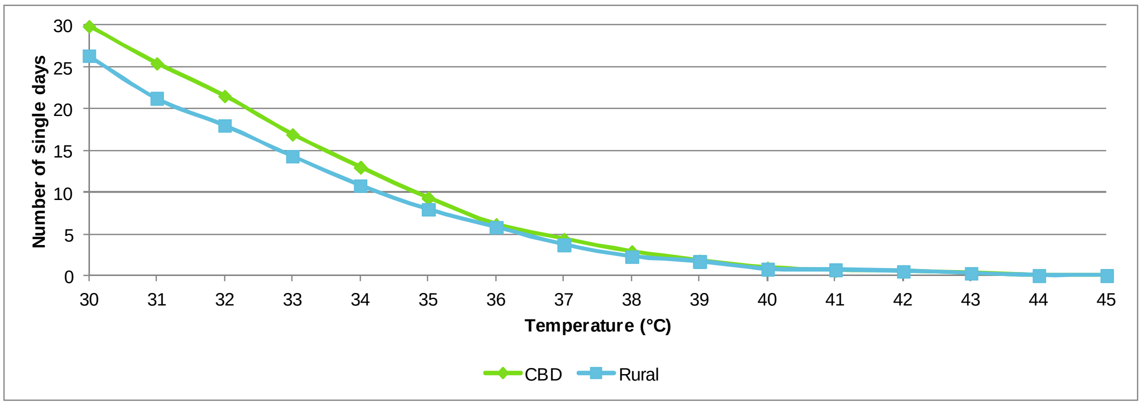
With an understanding of these relationships, the next step is to describe and quantify the economic impacts of the heat, heatwaves, and the UHI effect and to assess how these may change over time with a changing climate, urban form, and population within the City's boundaries, to answer the following question (relating to the bottom half of Figure 15):

- What are the current and projected economic costs of the heat, heatwaves, and the Urban Heat island effect, assuming no additional steps are taken to mitigate against it?

5.2.1 General Approach

As discussed in Section 2.1, our analysis has estimated the effect of the UHI by assessing the additional number of days due to UHI that exceed each temperature threshold band above 30 degrees, based on historical data (see Figure 16).

Figure 16 Number of days exceeding 30°C and above between 1999 and 2010



This is then used to estimate additional days due to UHI *within* each temperature band. For example, we are expecting 1 more day per year at 35 degrees C within the urban area than outside of it – and therefore due to the Urban Heat Island effect.

The economic analysis aims to estimate the monetary impact of these additional days (and sequences of days). For example, if we know that the health impacts of a 35 degree day cost the Melbourne community $10,000, then on average we expect $10,000 (1 day x $10,000) to occur each year as a result of the UHI effect.

A similar approach has been taken for heatwaves, and applied where a relationship between heatwaves and impacts could be established. For the purpose of this study, a heatwave has been defined as a 3 day sequence of events with day time temperatures greater than 35 degrees C.

These impacts are then projected out to 2051 taking into account climate change impacts and population growth, and discounted to obtain a Present Value of economic impacts of the UHI. As discussed in Section 2.5, urban development is expected to have a negligible effect during the assessment period (but may become significant over a longer time scale).

5.2.2 UHI Scenarios Assessed

The Urban Heat Island effect has been assessed under two different greenhouse gas emission (GHG) scenarios:

- A1G – a lower GHG scenario
- A1FI – a higher GHG scenario (see Appendix B for results)

These are described in more detail in Section 2.3.1.

5.2.3 Discount Rate

Discounting is standard procedure in economic assessments to add and compare costs and benefits that occur at different points in time, allowing a comparison of future costs and benefits against today's costs and benefits (Garnaut, 2010).

The choice of discount rate for climate adaptation projects is important. Standard infrastructure projects currently use a real (inflationary adjusted) discount rate between 6% and 7%, the Victorian State Government typically uses 6.5%, while Infrastructure Australia uses a 7% discount rate. However, it is common for projects with long term social and environmental impacts, such as those relating to climate change, to adopt a lower discount rate. For example, in the Garnaut Climate Change review, Garnaut argues for adoption of a social discount rate between 1.4% and 2.7%. The Stern Review on the Economics of Climate Change (2006) adopted a discount rate of between 1.4% and 1.7%.

This study has utilised a 'middle-ground' discount rate of 3%, with sensitivity testing of results using 1.5% and 6% discount rates to assist decision making.

5.2.4 Population growth

The population growth projections used for this analysis are presented Table 6.

Table 6 Population growth projections

Population Centre	Age	Population in 2011	Population in 2031	Population in 2051
Metropolitan Melbourne		4,137,432	5,411,938	6,471,050
City of Melbourne	0 to 4	3,904	7,331	No projection available
	5 to 11	1,939	4,557	
	12 to 17	4,247	7,786	
	18 to 24	24,336	41,714	
	25 to 34	29,678	51,312	
	35 to 49	17,001	34,563	
	50 to 59	7,413	15,303	
	60 to 69	5,466	10,329	
	70 to 84	3,332	7,318	
	85 and over	846	1,115	
	ALL	**98,162**	**181,326**	**216,811**

Source: Victorian in Future 2012

5.3 Health

5.3.1 Description of Economic Impacts of Heat-Related Health Issues

The health impacts of high temperatures can have lead to significant economic impacts for society. These impacts essentially fall into two categories:

- The costs in responding and treating heat-affected members of the community
- The non–monetary burden on those whose health is negatively impacted by hot conditions.

To quantify the latter requires an understanding of people's willingness to pay to avoid trips to hospital, treatment by doctors, and general reduction in well-being – and is an additional impact to what they actually pay for these health services. No attempt has been here made to quantify these non-monetary impacts.

The costs in responding and treating heat-affected members of the community include:

- Cost associated with ambulance services
- Costs associated with non-hospital medical services
- Cost associated with hospitalisation of patients due to heat related illness
- Cost associated with the loss of lives due to increased weather temperature.

Cost of Ambulance Services

Ambulance service in the City of Melbourne is provided by Ambulance Victoria. As of 1/1/2012, the ambulance fees for cases that require road transport is set at $966.25 and for cases that do not require road transport is set at $291.57[6].

Cost of Medical Services (non-hospital)

Treatment for heat-related issues by a general practitioner at a clinic within normal working hours can cost anywhere between $16.30 and $101.55, depending on level of care and treatment required.[7]

Fee associated with locum (afterhours) medical services ranges from $129.40 to $147.20 (unsocial hours). Unsociable hours are between 11pm to 7am[8]. Since no data was available on numbers of people treated for heat-related illnesses in general practitioner's clinics, no costs have been investigated.

Cost of Hospital Services

The cost associated with providing hospital services is estimated to be $3,852 per treatment episode for a public hospital and $3,606 per treatment episode for a private hospital in Victoria (Productivity Commission, 2009). For the purpose of estimating cost associated with providing hospital services for heat related illness, the per episode cost includes costs related to general hospital, pharmacy, emergency, medical & diagnostics, and capital costs. Costs related to providing prostheses are not included as they are unlikely to be relevant for heat-induced treatment. A breakdown of each cost component for the overall hospital services is presented in Table 7.

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[6] Hospital and medical costs, Department of Health, http://www.health.vic.gov.au/ambulance/fees.htm, 2012
[7] Medicare benefits Schedule Book – Operating from 1 March 2012, Australian Government Department of Health and Ageing, pp95-96
[8] ibid, Pg.140

Table 7 Cost component of hospital services for per case-mix adjusted basis in Victoria, 2007/08

Cost component	Public	Private
General hospital	$2,106	$2,004
Pharmacy	$235	$87
Emergency	$251	$50
Medical & diagnostics	$900	$1,226
Capital	$359	$240
Total	**$3,852**	**$3,606**

Source: Productivity Commission 2008

Loss of life

The economic impact of the loss of life due to heat-related impacts can be estimated in monetary terms based on the value of a statistical life. The value of statistical life is an estimate of the economic value society places on (society's willingness to pay for) reducing the average number of deaths by one. The Australian Government suggests a value of $3.5 million (in 2007 dollars) per statistical life is appropriate, based on a number of studies covering different techniques aimed at estimating society's willingness to pay to avoid the loss of a life[9]. A related concept is the *value of statistical life year*, which estimates the value society places on reducing the risk of premature death, expressed in terms of saving a statistical life year. The aforementioned study suggests a value of $151,000 (2007 dollars) per expected remaining year of life.

5.3.2 Assessment of Economic Impacts

This study quantified the following health related impacts of UHI effect on the City of Melbourne:

- Ambulance attendance to heat related illness, requiring transport to hospital. We assume that all of these cases were transported to the emergency department
- Ambulance attendance to heat related illness, requiring on the spot treatment
- Presentation to emergency department for heat related illness for those aged between 60-74 years and 75 years and older. This was due to lack of data availability for other age groups
- Mortality.

In order to quantify the number of above mentioned incidents that would occur in City of Melbourne, we ascertained the historical relationship between average daily temperature and incidents. These relationships were estimated using a published report from Department of Human Services on the health impacts of 2009 heat wave in metropolitan Melbourne. The Department of Health report found the vast majority of health impacts occur to people within their own residence. The estimated parameters for this relationship are summarised in Table 8. Further detail is provided in Appendix A.

Table 8 Health impact parameters

	Incidence rate	Unit
Ambulance Attendance - Heat related	0.09	Per 100,000 persons per 1 degree above 30.0
Ambulance Attendance - Heat Wave	1.48	Per 100,000 persons per number of days in heat wave (i.e. 3 consecutive days above 35.0)
Transported to hospital	80%	Assumed treated in Emergency Department
ED Presentations, aged 64-74 yrs	0.52	Per 100,000 persons per 1 degree above 30.0
ED Presentations, aged 74 yrs +	3.82	Per 100,000 persons per 1 degree above 30.0
Mortality	0.08	Per 100,000 persons per 1 degree above 30.0

[9] Value of statistical life – Best Practice Regulation Guidance Note, Office of Best Regulation Practice, Department of Finance and Deregulation, 2008

The estimated incident rates outlined above, along with population projections by age group for the City, were then applied to the number of additional days of high temperature attributable to the UHI effect.

This allowed a projection of the number of incidents attributable to the UHI each year out 2051.

The dollar costs described in Section 26 were applied (after converting to 2012 dollars using ABS published CPI data for metropolitan Melbourne) to monetise the health and mortality costs attributable to the UHI effect on the City of Melbourne community. Mortality impacts were calculated assuming that 75% of heat-related deaths occur in people who are 65 year or older (Department of Health information shows that between 65% and 90% of mortalities that occurred during previous heat were people aged 65 and over). The cost of mortality for this group has been estimated based on the value of statistical life and an assumed life expectancy of 82 years old (World Bank, 2012). The cost of mortality has therefore been assumed to be $2.1 million for this age group. The cost of mortality for people aged less than 65 years has assumed to be $3.5 million as discussed in Section 5.3.1.

The estimated economics impacts of heatwave events, including the costs attributable to the UHI effect, are summarised in Table 9.

Table 9 Economic assessment of Health Impacts – Heatwave impacts

Impact of Heatwaves (3 consecutive days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
COST OF HEATWAVE					
Ambulance Attendance - With Transport	21,000	66,400	105,400	2,676,700	1,389,200
Ambulance Attendance - On the spot treatment	1,200	3,900	6,200	157,400	81,700
Emergency Department Presentations, 64+ yrs	1,600	6,200	9,300	239,600	123,900
Mortality	7,202,600	22,767,900	36,128,500	917,159,700	476,009,900
TOTAL	*7,226,400*	*22,844,500*	*36,249,400*	*920,233,300*	*477,604,800*
COST OF HEATWAVE ATTRIBUTABLE TO UHI:					
Ambulance Attendance - With Transport	6,500	20,800	33,000	836,100	433,700
Ambulance Attendance - On the spot treatment	400	1,200	1,900	49,200	25,500
Emergency Department Presentations, 64+ yrs	500	1,900	2,900	74,800	38,700
Mortality	2,222,500	7,122,100	11,292,200	286,502,700	148,613,300
TOTAL	*2,229,900*	*7,146,100*	*11,330,000*	*287,462,900*	*149,111,300*

The economic impacts of single day heat events, including the costs attributable to the UHI effect, are presented in Table 10.

Table 10 Economic assessment of Health Impacts – Single Day Impacts

Impact of single hot days (single days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
SINGLE DAY IMPACT:					
Ambulance Attendance - With Transport	10,000	27,400	40,400	1,080,300	569,300
Ambulance Attendance - On the spot treatment	600	1,600	2,400	63,500	33,500
Emergency Department Presentations, 64+ yrs	4,200	14,800	20,500	556,700	292,000
Mortality	19,673,300	54,114,200	79,838,400	2,134,494,200	1,124,965,800
TOTAL	*19,688,100*	*54,158,000*	*79,901,600*	*2,136,194,700*	*1,125,860,600*
SINGLE DAY IMPACT ATTRIBUTABLE TO UHI:					
Ambulance Attendance - With Transport	1,300	3,200	4,600	127,100	67,600
Ambulance Attendance - On the spot treatment	100	200	300	7,500	4,000
Emergency Department Presentations, 64+ yrs	600	1,700	2,300	65,400	34,600
Mortality	2,606,600	6,373,800	9,135,600	251,062,800	133,643,200
TOTAL	*2,608,600*	*6,379,000*	*9,142,800*	*251,262,700*	*133,749,400*

A summary of total heat impacts (heatwave and singular days) and the component of these that is attributable to the UHI effect is presented in Table 11.

Table 11 Summary of the cost of heat impacts on health

	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
TOTAL HEAT IMPACTS (inc. UHI)	*26,914,500*	*77,002,500*	*116,151,000*	*3,056,428,000*	*1,603,465,400*
TOTAL UHI IMPACTS	*4,838,500*	*13,525,000*	*20,472,800*	*538,725,600*	*282,860,600*

5.4 Transport operation and infrastructure

5.4.1 Description of Economic Impacts

The economic impacts of disruptions to transport systems arise as a result of:

- Commuter delays;
- Repair costs; and
- Flow-on impacts to productivity.

The impact on individual commuters as a result of delays is dependent on the time of delay and the value that commuters place on their time. A number of studies have identified the value of time lost due to unexpected delays. Hensher (1994) found that the value of lost time due to delay ranged between 44% and 88% of the commuter's wage rate for the period of delay. Miller (1996) undertook a similar study, finding that commuter's willingness to pay to avoid unexpected delays ranged between 55% and 75% of the commuter's wage rate for the period of delay. Based on this, AECOM estimated the value of lost time at approximately $0.30 per minute. This and other details relating to the economic assessment are discussed further in Appendix A.

As discussed, the tram system has proven to be relatively resilient to hot weather conditions. Although there are reports that trams were forced to slow due to the effects of the heat during the heatwave, there is no evidence to suggest that this resulted in significant delays to commuters. Since the temperature experienced during the heatwave were extreme, it is reasonable to assume that there are also minimal impacts on commuters for singular days of high temperatures.

Repairs to affected train and tram tracks are minimal in nature, and mostly consist of hosing down buckled tracks to cool them off, which reverses the buckling effect. Although air-conditioning systems have been prone to failure during hot weather, these effects are temporary and operation returns to normal once temperatures cool. The costs of repairing road vehicles that have overheated are likely to be both significant and highly variable depending on the type of problem. Data to support this is, however, limited and therefore no assessment has been made.

Although the lost value of commuter's time in part reflects the lost production available by these commuters, there are additional flow-on impacts that ripple through the economy. Reductions in productivity in one sector lead to reduced outputs and productivity in other sectors. Productivity is also affected in numerous other ways when the transport system is disrupted by heat. Delays on public transport system may encourage more people to drive, which clogs up the road network, increasing existing road commuters travel times and reducing the efficiency by which other goods and services can be transported. Vehicles that breakdown due to heat exacerbate these impacts. These productivity impacts are extremely difficult to measure and would require complex modelling that is beyond the scope of this study.

5.4.2 Assessment of Economic Impacts on Transport

This study quantified the rail commuter delays only. It is recognised that productivity impacts and delays to road users can also be substantial, however, the lack of any readily available data means that these remain unquantified.

AECOM undertook a study in 2011 to investigate the impact of hot weather on metropolitan Melbourne's urban commuter rail system. The quantified impacts in terms of passenger weighted delay minutes (aggregated total of time of delays by number of passengers delayed) are shown in Table 12. It is not possible to proportionally attribute delay times to individual causes of failure with the information available, hence no assessment of planned mitigation measures has been incorporated into the analysis.

Table 12 Passenger weighted delay minutes of urban commuter rail system (2000- 2010)

Temperature thresholds	Degrees C	PWDM per event (mins per day across metropolitan Melbourne)
Single Days	>34.5 to 37	91,702
	37 to 40	277,313
	>40	490,092
Three consecutive days	>34.5 to 37	507,463
	37 to 40	1,021,273
	>40	3,599,598

City of Melbourne accounts for around 13% of metropolitan wide commuter train tracks. In order to quantify the rail commuter delays due to UHI effect in City of Melbourne, the proportion of metropolitan rail tracks in the City of Melbourne along with the estimated increase in daily temperature in City of Melbourne due to UHI effect was used to estimate the total passenger weighted delay minutes. This assumes for simplicity that all parts of the system have an equal chance of being impacted by heat, and therefore 13% of impacts are due to faults within the City for a given temperature across the system. The higher impacts due to the UHI are then accounted for. Note that this does not assume that the impacts accounted for are incurred only within the City, but rather that the direct causes are within the City.

The value of time of $0.30 ($0.302 in 2012 dollars) per minute discussed in Section 5.4.1 was used to monetise the impacts.

The cost impacts of heatwaves, including the cost attributable to the UHI effect, are summarised in Table 13.

Table 13 Economic assessment of heatwave impacts on Melbourne commuter trains

Impact of Heatwaves (3 consecutive days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
COST OF HEATWAVE					
Delayed Travel Time	27,000	132,400	283,800	6,042,500	2,978,000
TOTAL	*27,000*	*132,400*	*283,800*	*6,042,500*	*2,978,000*
COST OF HEATWAVE ATTRIBUTABLE TO UHI:					
Delayed Travel Time	6,700	43,400	81,000	1,821,400	904,900
TOTAL	*6,700*	*43,400*	*81,000*	*1,821,400*	*904,900*

The cost impact of single days above 30 degrees is presented in Table 14, including the cost attributable to the UHI effect.

Table 14 Economic assessment of single hot day impacts on Melbourne commuter trains

Impact of single hot days (single days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
SINGLE DAY IMPACT:					
Delayed Travel Time	$83,800	$317,800	$604,400	$13,799,300	$6,958,500
TOTAL	*$83,800*	*$317,800*	*$604,400*	*$13,799,300*	*$6,958,500*
SINGLE DAY IMPACT ATTRIBUTABLE TO UHI:					
Delayed Travel Time	$14,600	$47,600	$91,500	$2,097,000	$1,062,800
TOTAL	*$14,600*	*$47,600*	*$91,500*	*$2,097,000*	*$1,062,800*

A summary of total heat impacts (heatwave and singular days) and the component of these that is attributable to the UHI effect is presented in Table 15Table 11.

Table 15 Summary of heat impacts on Melbourne commuter trains

	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
TOTAL HEAT IMPACTS (including UHI)	*$110,800*	*$450,200*	*$888,200*	*$19,841,800*	*$9,936,500*
TOTAL UHI IMPACTS	*$21,300*	*$91,000*	*$172,500*	*$3,918,400*	*$1,967,700*

5.5 Energy Demand and Infrastructure

5.5.1 Description of Economic Impacts on Energy Demand and Infrastructure

Through raising average temperatures in the City and consequently changing patterns of energy demands, the UHI can have an economic impact on the supplier of energy in a number of ways:

- For users:
  - Cost increase due to increased energy use for cooling in summer
  - Cost saving due to reduced need to power heating equipments in winter.
- For suppliers:
  - Cost increase associated with expanding network capacity to cater for an increased level of maximum demand in summer
  - Cost increase associated with maintenance and repair cost driven by greater chances of network overload in summer.

Estimating the cost associated with changed energy demand can be achieved by applying the appropriate energy prices to the difference in energy consumed. Retail electricity prices vary over time and across different retailers, Essential Services Commission publishes a retail energy price review on an annual basis. Table 16 provides an average price from all retailers by Citipower.

Table 16 Retail energy price in the City of Melbourne

Year	Peak ($ per kWh)	Off-peak ($ per kWh)
2008/09	0.2101	0.0980
2009/10	02413	0.1054
2010/11	0.2524	0.1043

Source: Essential Services Commission (Vic) & AECOM analysis

The projected growth in real electricity prices used within this analysis are presented in Table 17.

Table 17 Projected growth in real electricity prices

Year	Real Price Growth
2012	-
2013	6%
2014	-0.80%
2015	-8%
2016	1.80%
2017	1%
2018	0.50%
2019	0.50%
2020	0.20%
2021	0.20%
2022+	0.20%

Source: Australian Energy Market Operator (AEMO), 2012

Estimates of costs per fault in the electricity network that services City of Melbourne is provided in Table 18 expressed in terms of the service order costs, in 2009 dollars.

Table 18 Maintenance cost per fault in the electricity network

Event type	Opex	Capex	Total
Cost per HV service order	$369	$2,360	$2,736
Cost per LV service order	$812	$713	$1,525

Source: AECOM 2009, data supplied by Citipower

The cost for increasing the electricity network capacity has previously been estimated by AECOM (2011)[10]. The cost involves two components: the cost for increasing transmission capacity and the cost for increasing distribution capacity. Typical transmission infrastructure includes overhead and underground cable and transmission lines and transmission towers, while distribution infrastructure includes terminal stations and transformers.

The cost estimates for upgrading the Citipower network capacity is provided in Table 19.

Table 19 Cost for upgrading electricity network capacity

Infrastructure category	Estimated Capex / Growth ($M / MW)
Transmission infrastructure	0.47
Distribution infrastructure[11]	3.3
Total	**3.77**

Source: AECOM

5.5.2 Assessment of Economic Impacts

This study quantified the economic impact of the UHI on:

- changes to energy demand
- increased maintenance cost due to faults in the electricity network.

As discussed in Section 18 and Appendix C, the retail price of electricity incorporates cost recovery for infrastructure upgrades. The effects of additional peak demand increases due to unexpected temperature increases would have the effect of requiring upgrades to occur sooner. The cost impact is therefore the opportunity cost of having to commit funds earlier than planned. To quantify this would require an analysis of all future infrastructure requirements, including costs and timing, in cases with and without the increase in demand due to temperature. The level of detail and resources to undertake this analysis is beyond the scope of this project.

Changes to energy demand

The relationship between City-wide energy use and temperature (average daily temperature) is presented in Table 20 (Citipower, 2009).

Table 20 Temperature- energy demand relationship in Melbourne

Energy	GWh	Unit
Energy use - Cooling Degree Days	0.228	GWh per 1 degree above 20 degrees
Energy use - Heating Degree Days	0.283	GWh per 1 degree below 16 degrees
% Citipower connections in City of Melbourne	60%	

Source: Citipower 2009

[10] AECOM, *Impact of Electric Vehicles and Natural Gas Vehicles on the Energy Markets*, 2011

[11] The cost for upgrading transmission infrastructure for Citipower is not directly available. This figure, the estimate for upgrading transmission infrastructure of SP Ausnet in Victoria, is applied as a substitute.

The energy demand unit rate presented in Table 20, along with the estimated increase in daily temperature due to climate change and the UHI effect, was used to estimate the increase in energy demand during hot days, and decrease in energy demand during winter (due to days below 10 degrees).

The assessed change in temperatures were based on current and projected *average* daily temperatures for each season, as opposed to the peak daily temperature information used to calculate most of the other impacts in this study. It is therefore not possible to estimate heatwave impacts, as these pertain to a sequence of peak temperatures.

The estimated change in energy demand for 2030 and 2050 also incorporated growth in urban development in City of Melbourne. The rate of growth in urban development was proxied using current and projected population growth in the City of Melbourne.

The peak and off-peak retail energy price as reported described in Section 5.5.1 was used to derive a weighted peak/ off-peak blended rate of $0.17 per kWh (in 2012 dollars) The resultant increase in energy cost during summer and energy cost savings during winter is summarised in Table 21 (note that a negative value indicates a cost to society).

Table 21 Economic assessment of impacts on energy demand

Impact of single hot days (single days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
SINGLE DAY IMPACT:					
Energy demand from temperature > 30 degrees	$2,697,700	$4,423,900	$6,184,300	$180,889,000	$99,251,500
TOTAL	*$2,697,700*	*$4,423,900*	*$6,184,300*	*$180,889,000*	*$99,251,500*
SINGLE DAY IMPACT ATTRIBUTABLE TO UHI:					
Increased energy demand	2,697,700	4,423,900	5,598,500	174,123,300	96,619,900
Reduced energy demand on cold days (benefit)	- 4,679,600	- 4,640,900	- 4,497,300	- 184,345,000	- 110,159,700
TOTAL	*- 1,981,900*	*- 217,000*	*1,101,200*	*- 10,221,700*	*- 13,539,800*

The above analysis shows that the resultant savings from energy consumption due to reduction in heating demand is slightly higher than the increase in cost from energy use due to increase in cooling degree days. This is because the UHI effect in the City of Melbourne leads to a higher decline in number of days with average temperatures below 10 degrees when compared to the increase in number of days above 30 degrees.

Note that this does not suggest that energy use overall is higher in winter, or that heating buildings in the winter uses more energy than cooling them in the summer. It merely shows that the UHI effect overall reduces the energy requirements of the city over the year. The results show that this effect is reversed by 2050, with a net increase in the cost of energy demand with climate change and the UHI effect.

It is worth noting that increased use of air-conditioning during hot days also has a feedback effect on the UHI effect as it creates additional heat outside the buildings. However, this feedback has not been incorporated in the modelling of the UHI effect.

Increased maintenance cost

To estimate the increase in maintenance cost due to faults in the electricity network, we applied historic records of high voltage and low voltage faults for different temperature bands presented in Table 22, (Citipower, 2009).

Table 22 Average number of faults per day by daily temperature

Maximum daily temperature range per year	Daily average number of high voltage faults	Daily average number of low voltage faults
30 – 35 ºC	0.3	1.9
35 – 40 ºC	1.3	7.5
>40 ºC	0.7	8.4

Citipower also advises that it costs around $2,942 (2012 dollars) per high voltage fault and $1,640 (2012 dollars) per low voltage fault to repair the faults. In addition, the associated downtime will also lead to lost earnings to Citipower, however, it has not been possible to quantify this with the data available.

Similar to the approach to estimate changes in energy consumption, the estimated increase in daily temperature due to UHI effect along with above reported average daily faults and cost per fault were used to estimate the economic cost of increased maintenance. In addition, we used the rate of growth in projected population in the City to allow for growth in urban development.

The cost impacts of heatwaves, including the cost attributable to the UHI effect, are summarised in Table 23.

Table 23 Economic assessment of heatwave impacts on electricity infrastructure

Impact of Heatwaves (3 consecutive days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
COST OF HEATWAVE					
High Voltage Faults	13,700	47,400	72,300	1,863,300	967,200
Low Vaultage Faults	49,300	88,400	109,800	3,412,900	1,884,800
TOTAL	*63,000*	*135,800*	*182,200*	*5,276,200*	*2,852,000*
COST OF HEATWAVE ATTRIBUTABLE TO UHI:					
High Voltage Faults	3,200	12,000	18,800	474,900	244,900
Low Vaultage Faults	10,900	22,100	28,100	846,800	462,300
TOTAL	*14,000*	*34,200*	*46,900*	*1,321,700*	*707,200*

The cost impact of single days above 30 degrees is presented in Table 24, including the cost attributable to the UHI effect.

Table 24 Economic assessment of single hot day impacts on electricity infrastructure

Impact of single hot days (single days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
SINGLE DAY IMPACT:					
High Voltage Faults	38,700	101,800	151,700	4,048,800	2,136,800
Low Vaultage Faults	134,100	211,700	276,300	8,477,600	4,702,400
TOTAL	*172,900*	*313,500*	*428,000*	*12,526,300*	*6,839,200*
SINGLE DAY IMPACT ATTRIBUTABLE TO UHI:					
High Voltage Faults	3,300	7,300	10,600	292,100	156,300
Low Vaultage Faults	11,400	11,000	10,700	439,800	263,400
TOTAL	*14,700*	*18,300*	*21,300*	*731,900*	*419,700*

A summary of total heat impacts (heatwave and singular days) and the component of these that is attributable to the UHI effect is presented in Table 25.

Table 25 Summary of impacts on electricity infrastructure

	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
TOTAL HEAT IMPACTS (including UHI)	*235,900*	*449,300*	*610,100*	*17,802,500*	*9,691,100*
TOTAL UHI IMPACTS	*28,700*	*52,400*	*68,200*	*2,053,600*	*1,126,900*

5.6 Anti-Social Behaviour

5.6.1 Description of Economic impacts of Anti-Social Behaviour

Criminal activities can impose significant costs on society in the form of damages and costs involved in addressing and preventing crime, including policing and maintaining the justice system.

The Australian Institute of Criminology (AIC) has estimated the direct cost of various types of crimes on the Australian society on a per-incident basis[12] (see Table 26). The aggregated estimated for indirect costs are also provided by AIC but they are not classified by crime type. However, it can be shown that these other costs represent approximately 40%of the overall crime cost in Australia and based on this information and the direct cost per crime type, AECOM has estimated the associated indirect costs for each crime category.

Table 26 Cost of crime in Australia (in 2005 dollars)

Crime category	Direct cost per incident	Indirect cost per incident	Total cost per incident
Homicide	$1,915,000	$1,298,087	**$3,213,087**[13]
Assault	$1,700	$1,152	**$2,852**
Sexual assault	$7,500	$5,084	**$12,584**
Robbery	$2,270	$1,539	**$3,809**
Burglary	$2,900	$1,966	**$4,866**
Theft from vehicles	$1,000	$678	**$1,678**
Shop theft	$125	$85	**$210**
Criminal damage	$1,250	$847	**$2,097**

Source: Australian Institute of Criminology, 2005 and AECOM analysis

5.6.2 Assessment of Economic Impacts

As discussed in Section 4.5, studies from the US suggests that collective crimes (e.g. riots), assault, domestic violence and non-aggressive crimes (such as burglary) have a positive linear relationship with hot weather. However, the relationship between hot weather and homicide, rape and robbery were deemed to be either inconclusive or 'possible'. Anderson et al (1997) found that on hot days, i.e. temperatures exceeding 90 degree F (32.2 degree C), for every 1 degree F increase in temperature, the number of violent crimes (homicide and assaults) increased by 3.68 per 100,000 persons.

To our knowledge, no such studies have been undertaken in the Australian context. Historic crime data by date could not be obtained to derive a relationship with historic temperatures.

For the purpose of this study, we have applied the violent crime rate as estimated by Anderson et al (1997). However, we have assumed that this rate applies only to assaults (i.e. homicides were not included for the Australian context). In other words, we have assumed that assaults in City of Melbourne will increase by 6.62 incidents per 100,000 persons for every 1 degree increase in temperature above 32 degrees.

According to Australian Institute of Criminology, the average direct and indirect cost of assault in Australia equates to $2,852 in 2005 dollars. This equates to a total cost of $3,432 in 2012 dollars.

The estimated incident rate at different temperatures, the average cost per incident, current and projected population for City of Melbourne, and estimated increases in daily temperature due to the UHI effect, were used to estimate the total cost of assaults in City of Melbourne.

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[12] Rollings, K, Counting the Costs of Crime in Australia: a 2005 update, Research and Public Polic Series No. 91, Australian Institute of Criminology, 2008,

[13] It is noteworthy that the cost of homicide on the society is substantially lower than the value of statistical life provided in Section 5.3.1. This is due to the fact that these two figures are taken from separate reports applying different methodologies in estimating the value of life. The inconsistency between the valuation of life is unlikely to affect the result of this study as homicide is a rare occurrence in the City of Melbourne and will not be included in assessing the impact of crim due to UHI effect.

The outcomes of the analysis are summarised below in Table 27 (note that a negative value indicates a cost to society). This suggests that over the next 40 years to 2051, the total economic and social cost of assaults in City of Melbourne attributable to the UHI effect is expected to be around $8.3 million in present value terms (based on a 3.0% real discount rate).

The cost impacts of heatwaves, including the cost attributable to the UHI effect, are summarised in Table 23.

Table 27 Economic assessment of heatwave impacts on crime

Impact of Heatwaves (3 consecutive days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
COST OF HEATWAVE					
Cost of assault	262,200	1,200,800	1,978,700	48,101,200	24,481,900
TOTAL	*262,200*	*1,200,800*	*1,978,700*	*48,101,200*	*24,481,900*
COST OF HEATWAVE ATTRIBUTABLE TO UHI:					
Cost of assault	94,900	410,400	657,600	16,273,700	8,325,900
TOTAL	*94,900*	*410,400*	*657,600*	*16,273,700*	*8,325,900*

The cost impact of single days above 30 degrees is presented in Table 28, including the cost attributable to the UHI effect.

Table 28 Economic assessment of single hot day impacts on crime

Impact of single hot days (single days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
SINGLE DAY IMPACT:					
Cost of assault	1,192,200	3,534,400	5,474,100	141,529,100	73,890,800
TOTAL	*1,192,200*	*3,534,400*	*5,474,100*	*141,529,100*	*73,890,800*
SINGLE DAY IMPACT ATTRIBUTABLE TO UHI:					
Cost of assault	167,400	402,500	606,800	16,225,700	8,596,100
TOTAL	*167,400*	*402,500*	*606,800*	*16,225,700*	*8,596,100*

A summary of total heat impacts (heatwave and singular days) and the component of these that is attributable to the UHI effect is presented in Table 29.

Table 29 Summary of impacts on crime

	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
TOTAL HEAT IMPACTS (including UHI)	*1,454,400*	*4,735,200*	*7,452,900*	*189,630,300*	*98,372,700*
TOTAL UHI IMPACTS	*262,200*	*812,900*	*1,264,300*	*32,499,400*	*16,921,900*

5.7 Trees and Animals

5.7.1 Description of Economic Impacts

As discussed in Section 4.6, trees and animals can be adversely affected in hot weather. This is particularly true if water availability is reduced.

The economic impacts of heat on trees and animals fall into the following key categories:

- Increased irrigation requirement
- If tree health suffers:
    - Increased costs of maintenance to return trees to health
    - Loss of amenity to the community
    - Reduced cooling capacity
    - Adverse effects to dependant native wildlife
    - Reduced provision of environmental services such as removal of air pollution, carbon sequestration, stormwater interception etc.
- Adverse health effects to pets, leading to increased veterinary costs.

The City of Melbourne have undertaken an assessment into the amenity value of Melbourne's urban forest as part of their Urban Forest Strategy. The total value of the City's 80,000 or so trees was estimated at $650 million, or approximately $8,125 per tree[14].

5.7.2 Assessment of Economic Impacts

For the purpose of this study, it is assumed that water availability will not be a significant issue over the study period due to water supply augmentations such as the desalination plant, and that tree health will largely be maintained by additional watering as temperatures increase. However it is recognised that some heat stress will occur regardless of water availability. City of Melbourne have estimated that approximately 20% of trees within the urban forest will die prematurely over the next two decades (1% per year) due to drought stress over the past decade. Given the improved water availability, for this assessment we have assumed that approximately one tenth of this rate of loss (0.1% per year) will occur due to heat stress. The value of this loss has been estimated based on the value per tree described above. No data is available to correlate this tree death with temperature, and it is therefore not clear how much of this is attributable to heatwaves or the UHI effect. It has therefore been treated as a heat impact in the quantification below. It is estimated that 10% of this impact is due to the UHI effect – an approximation based on the similar proportions of UHI impacts on irrigation costs and other categories of impacts investigated throughout this study.

The expected economic impacts of increased irrigative requirement under hot conditions are a function of the cost and volume of water used in maintaining tree health. No assessment of the impacts on animals has been undertaken due to a lack of relevant data.

For the purpose of quantifying the increase in demand for irrigating the City's water from potable sources, we have applied the relationship between water use and temperature as reported by Strelcova et. al. (2002) and discussed in Section 4.6. We have used the figure of 0.863 litres per day per degree, the lowest transpiration rate amongst the three trees that were examined in 'social positions', in recognition of the significant number of low water using native varieties within the City's urban forest. We have applied this transpiration rate to the estimated number of days above 30 degrees due to the UHI effect (and assumed that for these temperatures, irrigation is the primary source of water for the City's trees).

The Urban Forest Strategy indicates that there are 60,000 trees in the City's boundary on public land and another 20,000 trees in private land – a total of 80,000 trees within the City's boundary. The City of Melbourne have indicated they plan to plant 3,000 trees over the next decade as well as replacing deceased trees. This has been factored into the analysis.

According to South East Water Plan 2013 – 2018, non-residential water charge is expected to be $3.5 per kilolitre.

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[14] Recent assessments have indicated that this estimate may be conservative and that the number of trees within the City may be closer to 90,000 (70,000 of which are publicly owned), providing total economic benefits of approximately $750 million.

The estimated transpiration rate, along with current estimated number of trees and estimated increase in daily temperature due to the UHI effect, was used to estimate the total cost from increased need to irrigate the City's trees.

The impacts of heatwaves on the cost of irrigation are presented in Table 30.

Table 30 Economic assessment of heatwave impacts on irrigation for city's trees

Impact of Heatwaves (3 consecutive days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
COST OF HEATWAVE					
Cost of irrigation	10,600	21,900	29,100	851,700	462,100
TOTAL	*10,600*	*21,900*	*29,100*	*851,700*	*462,100*
COST OF HEATWAVE ATTRIBUTABLE TO UHI:					
Cost of irrigation	3,300	5,800	7,500	227,300	125,000
TOTAL	*3,300*	*5,800*	*7,500*	*227,300*	*125,000*

The impacts of single hot days on irrigation costs are presented in Table 31.

Table 31 Economic assessment of single hot day impacts on irrigation for city's trees

Impact of single hot days (single days > 30 degrees peak, aggregate over year)	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
SINGLE DAY IMPACT:					
Cost of irrigation	36,000	54,700	61,300	2,086,600	1,180,400
TOTAL	*36,000*	*54,700*	*61,300*	*2,086,600*	*1,180,400*
SINGLE DAY IMPACT ATTRIBUTABLE TO UHI:					
Cost of irrigation	3,100	2,900	1,900	105,600	65,900
TOTAL	*3,100*	*2,900*	*1,900*	*105,600*	*65,900*

The cost of heat-related tree deaths is presented in Table 32.

Table 32 Economic assessment of heat-related tree deaths

Other Heat Impacts	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
Total heat-related tree death	692,100	1,669,700	3,243,400	74,215,500	38,052,500
UHI attributable tree death	69,200	167,000	324,300	7,421,500	3,805,200

A summary of heat impacts on trees and animals is presented in Table 33.

Table 33 Summary of economic assessment of heatwave impacts on irrigation for city's trees

	Impact in 2012 ($)	Impact in 2030 ($)	Impact in 2050 ($)	Total, Undiscounted ($)	Total, Present Value @ 3% discount rate ($)
TOTAL HEAT IMPACTS (including UHI)	*738,700*	*1,746,300*	*3,333,800*	*77,153,800*	*39,694,900*
TOTAL UHI IMPACTS	*75,600*	*175,600*	*333,700*	*7,754,500*	*3,996,200*

5.8 Major Events

5.8.1 Description of Economic impacts

As discussed in Section 4.7, hot weather can lead to cancellation of events and reduction in attendances.

The potential economic impacts of hot weather on major events include:

- Lost revenue to event organisers through event cancellations and reduced attendances
- Lost consumer surplus[15] for would-be attendees that do not attend due to heat (through cancellations or otherwise)
- Discomfort and adverse health impacts for attendees and performers.

5.8.2 Assessment of Economic Impacts

Unfortunately, insufficient data was available to assess these economic impacts. We were unable to uncover any records of any major events being cancelled due to heat, and attendance numbers for events could not be ascertained.

Ideally, we would look to correlate attendances with temperatures and try to reveal thresholds for events beyond which people decide to stay home rather than attend. This would be used to assess the number of people that choose not to attend at different temperatures.

The value of tickets would be a lower bound for the value that the community gains from the event (bearing in mind consumer surplus – see footnote) and would be used to assess impacts for ticketed events. Events that are free to attend, such as the St Kilda Festival, would require an understanding of attendees willingness to pay (even though they do not have to). The travel cost method is one way in which this could be estimated, by assessing (via survey at the gate or something similar) the distance and mode by which attendees travelled to get to the event, and deriving the cost that this involves (time, fuel, public transport fare etc). Since they bear this cost to attend the event, it represents a minimum value that a rational attendee places on attending.

Health impacts would be assessed in a similar way to that undertaken in Section, and care would need to be taken to avoid double-counting health impacts already assessed.

5.9 Other Economic Impacts

There are a number of other economic impacts that have not been quantitatively assessed in this study. The more significant of these include:

- Impacts on the personal well-being of people within the City
- Impact on water demand
- Impacts on retail sales
- Vehicle fuel (from increased air-conditioning) and breakdown costs.

Economic impacts on personal well-being

The impacts on well-being could potentially be the greatest impact of higher temperatures resulting from the UHI, but are also the most difficult to quantify. The willingness to pay to avoid a loss of well-being is partly expressed via the costs associated with the use of air-conditioners – people use these to avoid feeling hot and bothered. However this only represents a portion of impacts on well-being. For many members of the community, air-conditioning is an ineffective or non-existent option, particularly those people who remain outdoors for work or other activities, or those in lower socio-economic circumstances that cannot afford it. The health impacts explored in this study are focussed on the costs of treating heat-related health conditions, but do not include the suffering experienced by those whose health is adversely affected.

The impacts on well-being have flow-on effects on productivity also – anyone who has to go to work after a hot, restless night can attest to this.

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[15] Consumer surplus is a measure of the net benefit that a consumer receives due to the fact that their willingness to pay for a good or service exceeds the amount they actually pay (the price).

Economic impacts on non-irrigative water demand and water infrastructure

The impact on water demand is difficult to determine based on historic information due to the influence of the drought and consequential water conservation measures (including water restrictions) on consumer behaviour. Many of these conservation behaviours are likely to persist for some time, despite the breaking of the drought and lifting of water restrictions. Improved water reliability measures mean that water restrictions are less likely to be required in the foreseeable future, and a more revealing data set should become available over the next decade with which to derive the temperature effects of water use.

Economic impacts on retail sales

The impact on retail sales cannot be ascertained with available data, and there are opposing factors that make it unclear whether heat is beneficial and detrimental to sales. For example, higher temperatures tends to drive people into air-conditioned shops and commercial facilities, however it is unclear whether this leads to increased sales, and if so, whether there is a corresponding dip in later sales as people manage their budgets over the year. Additionally, we would expect sales of drinks, ice creams, and the like to increase, however sales of hot foods, warm clothes etc would fall.

Economic impacts on vehicles

Insufficient data is available to ascertain the propensity for vehicles to break down at different temperatures. If such data were available, it may also be an unreliable guide to future impacts as older stocks of cars are replaced with newer, potentially more resilient models. The costs of such impacts are also highly variable.

Similarly, projections of the volumes of fuel used for vehicle air-conditioners are highly dependent on the size, age and types of cars that are present on today's roads and into the future. Quantification of these impacts has not been possible with the data available for this study.

Despite this, it is a reasonable to conclude that higher temperatures will lead to more frequent breakdowns due to overheating and additional fuel costs from increased use of air-conditioners.

Economic impact on tourism

The City of Melbourne is visited by a large number of people on a daily basis – see Table 34.

Table 34 Visitor number to the City of Melbourne

Visitor origin	Weekday visitor numbers
Metro visitors	154,000
Regional visitors	12,000
Interstate visitors	27,000
International visitors	31,000

Source: City of Melbourne, www.melbourne.vic.gov.au

Although no strong data exists to support the view, it is possible that an increase in extreme temperatures and heatwaves could cause a decline in the number of tourists visiting the City. If true, the UHI effect would exacerbate this impact. In addition, those that do visit may experience reduced amenity and potentially adverse health impacts.

5.10 Summary of Results

Based on the information available to quantify impacts, the net economic impact of hot weather within the City of Melbourne is estimated at $1,860 million as a present value[16] under the A1B Scenario, of which approximately $300 million (approximately 16%) is attributable to the UHI effect.

Of the total impact of hot weather, $508 million is due to heatwaves, of which $160 million is attributable to the UHI effect (ie additional heatwaves that occur in the City due to the UHI effect).

A summary of the results of this analysis are presented in Table 35 (total heat impacts) and Table 36 (UHI attributable impacts). The findings under the A1FI scenario are presented in Appendix B.

Table 35 Summary of economic assessment of heat impacts

Catgeory	Impact	Heat Impacts (Present Values discounted @ 3 %)		
		Heatwave costs ($)	Single hot day costs ($)	Total heat costs ($)
Health	Ambulance attendance - with transport	1,389,200	569,300	1,958,500
	Ambulance attendance - on the spot treatment	81,700	33,500	115,200
	ED Presentations, 64+ yrs	123,900	292,000	415,900
	Mortality	476,009,900	1,124,965,800	1,600,975,700
	TOTAL HEALTH	477,604,700	1,125,860,600	1,603,465,300
Transport	Delayed travel time	2,978,000	6,958,500	9,936,500
Energy	Energy demand from temperature > 30 degrees	Not assessed as heatwave impact	99,251,500	99,251,500
	Reduced energy demand on cold days (benefit)			Not applicable
	HV Faults	967,200	2,136,800	3,104,000
	LV Faults	1,884,800	4,702,400	6,587,200
	TOTAL ENERGY	2,852,000	106,090,700	108,942,700
Anti-Social Behaviour	Cost of assault	24,481,900	73,890,800	98,372,700
Trees and animals	Irrigation	462,100	1,180,400	1,642,500
	Heat-related tree death	Not assessed as heatwave impact	38,052,500	38,052,500
	TOTAL TREES AND ANIMALS	462,100	39,232,900	39,695,000
TOTAL IMPACTS		***508,378,700***	***1,352,033,500***	***1,860,412,200***

[16] Impacts assessed from 2012 to 2051 and discounted to present value using a 3% discount rate.

Table 36 Summary of economic assessment of heat impacts attributable to the Urban Heat Island Effect

Catgeory	Impact	UHI Attributable Heat Impacts (Present Values discounted @ 3 %)		
		Heatwave costs ($)	Single hot day costs ($)	Total heat costs ($)
Health	Ambulance attendance - with transport	433,700	67,600	501,300
	Ambulance attendance - on the spot treatment	25,500	4,000	29,500
	ED Presentations, 64+ yrs	38,700	34,600	73,300
	Mortality	148,613,300	133,643,200	282,256,500
	TOTAL HEALTH	149,111,200	133,749,400	282,860,600
Transport	Delayed travel time	904,900	1,062,800	1,967,700
Energy	Energy demand from temperature > 30 degrees	Not assessed as heatwave impact	96,619,900	96,619,900
	Reduced energy demand on cold days (benefit)	Not assessed as heatwave impact	- 110,159,700	- 110,159,700
	HV Faults	244,900	156,300	401,200
	LV Faults	462,300	263,400	725,700
	TOTAL ENERGY	707,200	- 13,120,100	- 12,412,900
Anti-Social Behaviour	Cost of assault	8,325,900	8,596,100	16,922,000
Trees and animals	Irrigation	1,180,400	65,900	1,246,300
	Heat-related tree death	Not assessed as heatwave impact	3,805,200	3,805,200
	TOTAL TREES AND ANIMALS	1,180,400	3,871,100	5,051,500
TOTAL IMPACTS		***160,229,600***	***134,159,300***	***294,388,900***

5.11 Discussion

The analysis reveals some interesting results about the expected economic impacts. Two of the key categories of impacts dominate the results: health, and energy.

The largest and most serious impact of an increasing UHI effect under climate change is the expected increase in deaths, which makes up roughly 86% of the total cost impacts due to heat, with an estimated economic cost of $1,600 million as a present value, and 96% of the costs attributable to the UHI effect at $280 million. This is reflective of the dangerous effect that extreme temperatures can have on human life (particularly the elderly and disadvantaged), the increasing number of such events as a result of climate change (and hence increasing number of heat-related deaths), and importantly, the high value that society places on preventing the loss of a human life. Other health impacts are minor in comparison, with a total impact due to heat across the other health categories of $2.5 million in present value terms, of which $0.6 million can be attributed to the UHI effect. Heatwaves make up about 30% of heat impacts on health, and 52% of the impacts attributable to the UHI effect.

The UHI effect produces both benefits and costs to society in terms of energy use and infrastructure expenditure. The benefits in terms of savings due to reduced heating requirements in winter due to the UHI are substantial (present value of $110 million), which offsets the additional energy costs in warmer months (present value of $97 million). This is partly due to the fact that the UHI effect is more pronounced at lower temperatures, and the energy requirement per degree difference from a person's comfort zone for heating and cooling is roughly similar. In simple terms, the UHI provides more beneficial warming energy in winter than is required to combat it in summer. The costs of networks faults in summer are small in comparison to these energy demand impacts.

The impacts of heat on trees and animals are also substantial, estimated at $40 million as a present value, of which $5 million is due to UHI effect. These impacts are dominated by the cost of tree deaths.

The costs of increased crime due to heat are also substantial, with a present value of $98 million. $17 million of these cost impacts are attributable to the UHI effect. Transport impacts are also significant, resulting in costs to the economy of almost $10 million in present value terms, of which $2 million is due to the UHI effect.

5.12 Sensitivity Analysis

There is recognised uncertainty in many of the parameters and assumptions used for this analysis. Greenhouse gas emissions are addressed via modelling of both A1B and A1FI scenarios (full results for the latter are presented in Appendix B). The purpose of the discussion here is to test the sensitivity of results to variations in some of the other key uncertainties.

An examination of the various cost and benefit items (see to Table 23 above) shows that over 95% of the cost associated with UHI is driven by mortality. This is followed by increased energy consumption for cooling and assaults. Table 24 below provides estimates of how Net Present Value estimates vary with the following changes in each of these variables:

- **Mortality**: mortality rate ranging from 0.04 person per degree over 30 degrees per 100,000 people, to 0.12 per degree over 30 degrees per 100,000 people (Table 37)
- **Mortality**: increase and decrease of value of statistical life and life year by 50% (Table 38)
- **Energy consumption during hot weather**: energy demand ranging from 0.114 GWh per degree over 30 degrees per day, to 0.342 GWh per degree over 30 degrees per day (Table 39)
- **Crime**: rate of assaults ranging from 3.31 assaults per degree over 32 degrees per 100,000 people, to 9.94 assaults per degree over 32 degree per 100,000 people (Table 40)

Table 37 Sensitivity analysis – mortality rate

	50% reduction in mortality rate (Present value @ 3% discount rate)		50% increase in mortality rate (Present value @ 3% discount rate)	
	Total Heat Impact ($)	UHI Attributable Component ($)	Total Heat Impact ($)	UHI Attributable Component ($)
Mortality Cost	800,487,900	141,128,300	2,401,463,600	423,384,800
Total Cost	1,059,924,400	153,260,700	2,660,900,100	435,517,200
% Change in Total Cost	57%	52%	143%	148%

Table 38 Sensitivity analysis – value of life

	50% reduction in value of life (Present value @ 3% discount rate)		50% increase in value of life (Present value @ 3% discount rate)	
	Total Heat Impact ($)	UHI Attributable Component ($)	Total Heat Impact ($)	UHI Attributable Component ($)
Mortality Cost	800,487,900	141,128,300	2,401,463,600	423,384,800
Total Cost	1,059,924,400	153,260,700	2,660,900,100	435,517,200
% Change in Total Cost	57%	52%	143%	148%

Table 39 Sensitivity analysis – energy consumption rate

	50% reduction in energy consumption rate during hot weather (Present value @ 3% discount rate)		50% increase in energy consumption rate during hot weather (Present value @ 3% discount rate)	
	Total Heat Impact ($)	UHI Attributable Component ($)	Total Heat Impact ($)	UHI Attributable Component ($)
Energy demand cost	49,625,700	48,309,900	148,877,200	144,929,800
Total Cost	1,810,786,400	246,078,900	1,910,037,900	342,698,800
% Change in Total Cost	97%	84%	103%	116%

Table 40 Sensitivity analysis – crime rate

	50% reduction in crime rate (Present value @ 3% discount rate)		50% increase in crime rate (Present value @ 3% discount rate)	
	Total Heat Impact ($)	UHI Attributable Component ($)	Total Heat Impact ($)	UHI Attributable Component ($)
Cost of assaults	49,186,300	8,460,900	147,559,000	25,382,900
Total Cost	1,811,225,800	285,927,800	1,909,598,500	302,849,800
% Change in Total Cost	97%	97%	103%	103%

The sensitivity analysis shows that the results are highly sensitive to changes in the mortality rate parameter, which suggests that this parameter should be a focus for further investigation if results are to be further refined. The other parameters are relatively insensitive in comparison.

As discussed in Section 5.2.3, the discount rate is also a source of considerable controversy and uncertainty. We have therefore estimated the total impacts using real discount rates ranging from 1.5% to 6.0% (see Table 41).

Table 41 Sensitivity analysis – Discount rate

Discount Rate, Real	Total Heat Impact (Present Value, $)	UHI Attributable Component (Present Value, $)
1.50%	2,527,699,300	405,999,400
3.00%	1,860,412,200	294,388,900
6.00%	1,101,181,100	168,596,600

The results are highly sensitive to the discount rate. This is not surprising, as the impacts of heat and the UHI grow considerably over time due to both climate change and population pressures, and hence the less influence the discount rate has on these distant impacts, the greater the present value.

5.13 Effects beyond 2051

The analysis presented here has considered modelling of impacts from 2012 until 2051, with the rationale that the uncertainties are too great to attempt to project beyond this.

It not unreasonable, however, to discuss what we might expect to occur beyond 2051.

The climate modelling provided by climate projections out to 2071 and shows an increasing number of higher temperature days. These are displayed in Table 42.

Table 42 Projected number of hot day events

Temperature thresholds		Average number of events per year for a given scenario			
		1971 - 2000 (historic average)	2030 (A1B)	2050 (A1B to A1FI)	2070 (A1B to A1FI)
Single days	30ºC	*30.3*	36.7	42.9-45.1	48.4-57.2
	35ºC	*9.5*	13	16.6-18.2	20.1-25.9
	40ºC	*0*	4	3.8-4.4	5.3-7.8
Three consecutive days	30ºC	*3.4*	4.8	5.6-6.1	6.9-9.1
	35ºC	*0.7*	1.1	1.6-1.7	1.9-2.8
	40ºC	*1.3*	2.3	0.1-0.2	0.2-0.5

In the absence of any steps to mitigate the UHI effect, by 2071 we would expect an additional 7 days per year over 35 degrees that would not be experienced by those outside of the City – i.e. due entirely to the UHI effect.

Population projections of the City of Melbourne are only available to 2051, at which point it is expecting there will be approximately 6.2 million people. Based on the growth rate implied in these projections, it is reasonable to assume that the City's population will be above 7 million people by 2071.

With the combination of an enhanced Urban Heat Island effect and a much larger population effected, we would expect to see an exponential increase in impacts across all categories discussed here.

6.0 Conclusion

6.1 Conclusions

The research and analysis undertaken has revealed a number of interesting observations and findings.

First, hot weather imposes significant economic costs on society. The analysis undertaken here estimates these impacts to be valued at more than $1.8 billion as a present value from impacts in the City of Melbourne alone. Almost one-third of this is due to heatwaves.

Second, Melbourne's Urban Heat Island has been shown to be a significant contributor to peak temperatures within the CBD. Based on hourly temperature data derived from both within the CBD area and a number of stations outside it, a UHI effect was derived over a range of temperatures. For temperature above 30 degrees C, this effect was shown to decrease as temperatures rise. When non-CBD areas experience a 30 degree day, the City experiences a 30.8 degree day – a UHI effect of 0.8 degrees C. This effect falls to about 0.5 degrees at 40 degrees C. UHI effects at extreme temperature are, however, more difficult to ascertain due to a reduced data set in this range.

These effects are expected to be exacerbated by climate change. Under CSIRO modelling and the derived UHI effect, the CBD is expected to experience 2.2 additional days per year that are greater than 35 degrees C than in non-CBD areas, and an additional heatwave (defined as three sequential days greater than 35 degrees C) every ten years compared to non-CBD areas.

The impacts of this additional hot weather within the City is expected to produce a range of impacts on health, transport operation and infrastructure, energy demand and infrastructure, trees and animals, and crime.

The vast majority of this is as a result of heat-related deaths, reflecting the dangerous effect that extreme temperatures can have on human life (particularly the elderly and disadvantaged), the increasing number of such events as a result of climate change (and hence increasing number of heat-related deaths), and importantly, the high value that society places on preventing the loss of a human life.

The economic cost of increased energy demand in the warmer months is offset by the benefits of reduced energy demand due to warmer condition that the UHI creates during colder winter months.

The total economic cost to the community due to this additional high temperatures caused by the Urban Heat Island effect is estimated to be approximately $300 million in present value terms.

This is a significant cost, and given the range of impacts that were not possible to quantify, this estimate could be considered conservative. In particular, impacts on personal well-being could potentially be the greatest impact of higher temperatures resulting from heat and the UHI, but are also the most difficult to quantify.

Sensitivity analysis found that the results are quite sensitive to assumptions and inputs pertaining to mortality and discount rate, indicating that it may be possible to increase the robustness of results with further understanding and refinement in these areas.

6.2 Limitations

This study has some limitations in relation to availability of appropriate data and information as well as inherent uncertainties. The most significant of these are discussed below.

Derivation of the UHI Effect

The UHI effect was derived based on hourly day-time temperatures from a single monitoring station in the CBD, and from three monitoring stations outside the CBD. This has resulted in the following limitations to the study:

- Variations in UHI effect across the CBD could not be assessed (however the patchiness and granularity of available information to assess impacts limits the usefulness of such data)
- Monitoring stations outside the CBD exist within areas with some urban development, albeit small relative to the city, which could potentially reduce the UHI differential
- Historic temperature data is very limited for more extreme weather events, particularly heatwaves, substantially reducing the certainty surrounding the derivation of the UHI effect for these events

- Night-time effects of the UHI were not possible to derive with the available data set and scope of this study

Climate modelling data

There is recognised uncertainty inherent in data produced by climate modelling that is more pronounced the further the projections are into the future. Confidence in the economic assessment is partially affected by this uncertainty. This has been addressed to an extent within this study by including the modelling of two greenhouse gas emission scenarios separately in the economic assessment, however it is recognised that considerable but unavoidable level of uncertainty remains.

It is also for this reason, coupled with other uncertainties, that this study has limited the period of assessment to 2051. However it is recognised that there is consensus that the impacts analysed in this study will not only exist beyond 2051, but will exponentially increase.

Impact data

Melbourne-specific information about heat impacts that could be used to correlate impacts with temperatures was generally hard to find, and where it did exist, was often not possible to obtain.

Where Melbourne-based information was available, much of it related to the 2009 heatwave, and hence many of the relationship derived were based on a limited dataset that included the 2009 heatwave and a few days either side of it.

In addition, it is recognised that overnight temperatures are a key element of some of the impacts of heat and the UHI. Very few studies and data include night-time temperatures in their assessments; data tends to be limited to daily impacts and peak day-time temperatures, with no further stratification beyond this.

Health is a key category affected by high overnight temperatures, particularly during heat waves. By assessing the impacts of heatwaves on health in this study, the overnight temperature effects are partially captured.

6.3 Recommendations

Based on the research and findings of this analysis, the following is recommended:

- We recommend further efforts to obtain the existing datasets that could not be obtained for this study, particularly the full dataset of health impacts and crime by date for the past decade, so that a more robust correlation between impacts and temperatures can be developed. Obtaining similarly detailed attendance information for major events would also improve the analysis. Further research into impacts of high overnight temperatures and the role of the UHI in these would also be beneficial.
- The economic impacts presented here indicate that the effects of the UHI are significant. Alone, however, they do not provide a case for action. The case for action must be made on an assessment of the *reduction in impact possible by undertaking various actions, relative to the cost of these proposed action*s. The assessment here provides a firm baseline for such a Cost Benefit Analysis. We therefore recommend that the information presented here be used in the development of a Cost Benefit Analysis of actions aimed at mitigating the UHI effect.

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Appendix A

Economic assessment steps

Appendix A Economic assessment steps

General

In general, the steps to undertaking the analysis are:

- For each of the impact categories, where possible, establish a relationship between physical impacts and temperatures, including sequences of temperatures to estimate heatwave impacts
- Establish economic parameters for the cost of impacts in unit terms that can be scaled. For example, $x per day per degree above 30 degrees.
- Assess the number of days, and sequences of days, expected in each of the temperature bands - both currently and under climate change conditions at 2030 and 2050. This is done within the CBD and outside the CBD to estimate the additional hot days that occur within the CBD due to the UHI effect
- Apply the established relationships to each of the days within the range of temperature bands to estimate total impacts now and in 2030 and 2050. Include escalations for increased populations and other growth factors where appropriate.
- Estimate economic costs of these impacts by applying economic parameters
- Interpolate between calculated years (ie between 2012 and 2030, and 2030 and 2050) to estimate annual costs to 2050.
- Discount results to present value using an appropriate discount rate.

Provided below is the relevant temperature data and projections used in the analysis.

Following these are some examples of calculations to provide a better understanding of how the economic impacts have been estimated.

Temperature and Climate Data

The analysis of the current UHI effect is based on weather data measured at Melbourne Regional Office in the CBD, and in three non-CBD areas; Melbourne Airport, Moorabbin Airport and Laverton RAAF base. Hourly temperature data has been obtained for each weather station from the Bureau of Meteorology for all available time periods. To provide consistent analysis, data sets are taken from 28 July 1998 up to 15 September 2011 – a period when all four weather stations provided consistently full data measurements for temperature. The average number of days per year and 3-day sequences per year within each of the temperature bands above 30 degrees (peak daily temperatures) is presented in Table 43.

Table 43 Annual number of peak temperature days

	CBD		Non-CBD	
Peak daily temperature	Average number of single days per year	Average number of consecutive (3) days per year	Average number of single days per year	Average number of consecutive (3) days per year
30	4.42	0.83	5.08	1.17
31	3.92	1.17	3.25	0.83
32	4.58	0.75	3.67	0.58
33	3.92	0.92	3.50	0.50
34	3.67	0.25	2.83	0.08
35	3.17	0.33	2.17	0.25
36	1.75	0.17	2.08	0.08
37	1.50	0.00	1.42	0.00
38	1.08	0.00	0.58	0.00
39	0.83	0.00	0.92	0.00
40	0.33	0.00	0.08	0.00

41	0.08	0.00	0.17	0.08
42	0.25	0.08	0.25	0.00
43	0.25	0.00	0.25	0.00
44	0.00	0.00	0.00	0.00
45	0.08	0.00	0.00	0.00
46	0.00	0.00	0.08	0.00
> 47	0.00	0.00	0.00	0.00

Projections of average number of days and 3-day sequences exceeding temperature thresholds per year, under the two emission scenarios, are presented in Table 44 to Table 47.

Table 44 CBD – Projected average number of single days exceeding temperature thresholds per year

Year	Emission Scenario	Number of single days exceeding temperature threshold (degrees)															
		30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
2030	A1B	41.6	37.2	31.0	25.4	20.6	15.2	10.4	9.4	7.1	4.2	2.8	1.3	0.8	0.3	0.1	0.0
2050	A1B	48.6	43.2	36.5	30.2	25.2	19.3	13.7	11.7	9.6	5.7	4.5	2.0	1.4	0.7	0.3	0.1
2050	A1FI	51.1	45.9	38.9	32.8	27.3	21.3	15.2	13.1	10.6	6.8	5.3	2.5	1.7	0.9	0.4	0.2
2070	A1B	54.8	49.3	41.8	35.2	30.0	23.5	16.9	14.8	12.0	7.8	6.3	3.3	2.1	1.3	0.7	0.3
2070	A1FI	64.8	58.5	50.2	42.0	36.5	30.2	22.0	19.3	16.3	10.4	9.3	5.1	3.9	2.4	1.5	0.8

Table 45 CBD – Projected average number of 3-day sequences exceeding temperature thresholds per year

Year	Emission Scenario	Number of 3-day sequences exceeding temperature threshold (degrees)															
		30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
2030	A1B	6.1	5.4	4.2	3.6	2.6	1.5	1.2	0.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2050	A1B	7.0	7.2	5.5	4.6	3.3	2.2	1.6	0.8	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0
2050	A1FI	7.7	7.8	6.3	5.4	3.6	2.4	1.7	0.9	0.6	0.4	0.2	0.1	0.0	0.0	0.0	0.0
2070	A1B	8.6	8.3	7.3	6.0	4.3	2.6	2.2	1.0	0.8	0.5	0.2	0.1	0.0	0.0	0.0	0.0
2070	A1FI	11.5	10.7	9.0	8.3	5.9	3.9	2.9	1.5	1.1	0.8	0.5	0.3	0.1	0.0	0.0	0.0

Table 46 Non-CBD – Projected average number of single days exceeding temperature thresholds per year

Year	Emission Scenario	Number of single days exceeding temperature threshold (degrees)															
		30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
2030	A1B	36.7	31.1	26.0	21.5	17.2	13.0	9.8	8.0	5.7	4.0	2.3	1.4	0.8	0.3	0.1	0.0
2050	A1B	42.9	36.1	30.6	25.6	21.0	16.6	12.9	9.9	7.7	5.4	3.8	2.2	1.4	0.7	0.3	0.1
2050	A1FI	45.1	38.3	32.6	27.8	22.7	18.2	14.3	11.1	8.5	6.5	4.4	2.8	1.7	0.9	0.4	0.2
2070	A1B	48.4	41.2	35.0	29.8	25.0	20.1	16.0	12.5	9.6	7.5	5.3	3.7	2.1	1.3	0.7	0.3
2070	A1FI	57.2	48.9	42.1	35.6	30.4	25.9	20.8	16.4	13.0	10.0	7.8	5.7	3.9	2.4	1.5	0.8

Table 47 Non-CBD – Projected average number of 3-day sequences exceeding temperature thresholds per year

Year	Emission Scenario	Number of 3-day sequences exceeding temperature threshold (degrees)															
		30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
2030	A1B	4.8	3.5	2.6	2.0	1.6	1.1	0.8	0.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2050	A1B	5.6	4.8	3.5	2.6	2.0	1.6	1.1	0.8	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0
2050	A1FI	6.1	5.2	4.0	3.1	2.2	1.7	1.1	0.9	0.6	0.4	0.2	0.1	0.0	0.0	0.0	0.0
2070	A1B	6.9	5.5	4.6	3.4	2.6	1.9	1.5	1.0	0.8	0.5	0.2	0.1	0.0	0.0	0.0	0.0
2070	A1FI	9.1	7.0	5.7	4.8	3.6	2.8	1.9	1.5	1.1	0.8	0.5	0.3	0.1	0.0	0.0	0.0

The average daily temperatures (as opposed to peak daily temperatures represented in the previous table) by season are presented for the CBD and non-CBD in Table 48 and Table 49 respectively.

Table 48 CBD – Average daily temperatures by season

Year	Emission Scenario	Average daily temperature (degrees) - Winter	Average daily temperature (degrees) - Spring	Average daily temperature (degrees) - Summer	Average daily temperature (degrees) - Autumn
2012		11.4	15.6	20.4	16.4
2030	A1B	11.5	15.7	20.7	16.5
2050	A1B	11.6	15.9	20.9	16.7
2050	A1FI	11.4	15.6	20.4	16.4
2070	A1B	11.6	15.9	21.0	16.8
2070	A1FI	11.7	16.1	21.2	16.9

Table 49 Non-CBD – Average daily temperatures by season

Year	Emission Scenario	Average daily temperature (degrees) - Winter	Average daily temperature (degrees) - Spring	Average daily temperature (degrees) - Summer	Average daily temperature (degrees) - Autumn
2012		10.4	14.6	19.6	15.6
2030	A1B	10.5	14.7	19.8	15.7
2050	A1B	10.6	14.9	20.1	15.9
2050	A1FI	10.4	14.6	19.6	15.6
2070	A1B	10.6	14.9	20.2	15.9
2070	A1FI	10.7	15.1	20.4	16.1

Health Impacts Assessment example

Example calculation – cost of mortalities from single hot days in 2030

Average rate of mortality is 0.08 people per 100,000 per day per degree above 30 degrees.

In 2030:

- Population is expected to be 177,348 people within the CBD. Therefore, it is expected that there will be 0.14 mortalities per day per degree above 30 degrees.
- It is expected that 4.4 days will be between 30 and 31 degrees in the CBD (41.6 days exceeding 30 degrees minus 37.2 days exceeding 31 degrees).
- There is therefore expected to be an average of 0.616 mortalities from days with temperature between 30 and 31 degrees.
- This calculation is repeated for all temperature intervals to estimate the total number of mortalities in 2030.
- The total number of mortalities is then multiplied by the real value of life estimate ($2.09 million) to estimate the total cost of mortality in 2030 from days above 30 degrees.

Transport Impacts Assessment example

Example calculation – cost of impacts of 3-day sequence of days between 37 and 40 degrees in 2030

The current average delay due to a heatwave consisting of a 3-day sequence between 37 and 40 degrees is 1,021,273 Passenger Weighted Delay Minutes (PWDM).

As an estimate of impacts due to heatwaves within the City of Melbourne, the proportion of track length (13%) within the City was used as a proxy. Delays due to heatwaves within the City in 2012 were therefore estimated at 133,949 PWDM.

In 2030:

- Patronage is expected to grow by 2.07 times over the period to 2030, increasing the PDWM per heatwave event to 276,893 PWDM.
- It is expected that there will be an average of 5.7 3-day sequences between 37 degrees and 40 degrees in 2030 (8.0 3-day sequences exceeding 37 degrees minus 2.3 3-day sequences exceeding 40 degrees).
- Therefore, it is expected that there will be 1,578,290 PWDM in 2030.
- The total PWDM is multiplied by the real value of one PWDM ($0.30) to arrive at an estimate of $476,654 in costs of delays due to 3-day sequences between 37 and 40 degrees.
- This process is also undertaken for 3- day sequences between 34 degrees and 37 degrees, and 3-day sequences greater than 40 degrees, to estimate the total heatwave impact in 2030.

Energy Impacts Assessment example

In contrast to the other impact categories, energy use relationships with temperature (heating degrees days and cooling degrees days) are expressed in terms of average daily temperatures rather than peak daily temperatures.

Example calculation – cost impacts of UHI in cooler months (Mid-November to Mid-March) in year 2012

- The number of heating degree days is calculated as the sum of the number of degrees below 16 degrees for each day in the cooler months of mid-March to mid-November. It is assumed for simplicity that this is exactly half of 365 days, and the months are of equal length. For example, heating degree days for December in the CBD are 4.6 degrees (16 minus 11.4) multiplied by 30.4 days (365 divided by 12), which equals 139.8 cooling degree days.
- This process is undertaken for all relevant days within the period for both within the CBD and outside the CBD.
- The difference in number of heating degree days between the CBD and non-CBD area is then attributed to the UHI effect. This number is estimated to be -156.6 additional heating degree days due to the UHI in 2012 based on this process – that is, there is a reduction in heating degree days of 156.6.
- The additional electricity requirement per heating degree day is approximately 0.1698 GwH per heating degree day (based on Citipower estimates and an estimated 60% of use from within the City of Melbourne)
- Therefore, approximately there is a reduction 26.59 additional GwH (156.6 multiplied by 0.1698) of electricity required during the cooler months due to the UHI.
- The cost of this in 2012 is approximately $4,679,600 based on a rate of $0.176 per KwH (blended peak and off-peak rate).

Anti-Social Behaviour Impacts Assessment example

Example calculation – cost of assaults from single hot days in 2050

- Population of City of Melbourne estimated to be 216,000 people by 2050 (based on extrapolation of 2031 population projections of the City by using 2051 Metropolitan projections and assuming that the proportion of Metropolitan Melbourne population contained within the City in 2031 is maintained in 2051.)
- Assumed 6.62 assaults per 100,000 people per degree above 32 degrees based on US study

- Number of assaults in 2050 is therefore estimated at 14.30 per degree above 32 degrees.
- The number of days between 34 and 35 degrees (for example)in 2050 is estimated to be 6.0 (27.3 days exceeding 30 degrees minus 21.3 days exceeding 34 degrees).
- The number of assaults is therefore estimated at 514.8 (14.30 assaults per degree above 32 multiplied by 6.0 days multiplied by 3 degrees)
- This calculation is repeated for all temperature intervals to estimate the total number of assaults expected in 2050.
- The total number of assaults is then multiplied by the real cost of an assault ($1,716 including direct and indirect component) to estimate the total cost of assaults in 2050 from single days above 30 degrees.

Trees and animals Impacts Assessment example

Example calculation – cost of irrigation demand from UHI effect on single hot days in 2030

- Current total number of trees estimated at 80,000
- Expected tree population at 2030 is estimated at 110,000 trees
- Irrigated water requirement on hot days (over and above naturally available water) is estimated at 0.863 litres per tree per degree above day above 30 degrees
- On a day between 38 and 39 degrees (for example), it is therefore estimated that irrigated water use is approximately 7.76 litres per tree.
- In 2030, the expected number of days between 38 and 39 degrees in the CBD is estimated at 2.9 (7.1 days exceeding 38 degrees minus 4.2 days exceeding 39 degrees). The estimated number of days within this temperature band outside the CBD is estimated at 1.7 days. The estimated number of additional days within this band in the CBD due to the UHI effect is therefore estimated 1.2 days.
- The total volume of water use due to the UHI from days between 38 and 39 degrees expected in 2030 is therefore estimated at 1,024,320 litres.
- This calculation is repeated for all temperature intervals to estimate the total volume of irrigated water use expected in 2030.
- The volume of irrigated water is then multiplied by the real cost of water in 2030 ($3.50 per kL) to estimate the total cost of irrigated water use in 2030 due to the UHI effect.

Appendix B

Economic Results - A1FI Climate Scenario

Appendix B Economic Results - A1FI Climate Scenario

The analysis was also undertaken under the higher GHG emission scenario of A1FI.

A summary of the results of this analysis are presented in Table 35 (total heat impacts) and Table 36 (UHI attributable impacts). Impacts are slightly higher due to increased warming under this scenario from 2030 onwards.

Table 50 Summary of economic assessment of heat impacts – A1FI Scenario

Catgeory	Impact	Heat Impacts (Present Values discounted @ 3 %)		
		Heatwave costs ($)	Single hot day costs ($)	Total heat costs ($)
Health	Ambulance attendance - with transport	1,445,300	583,600	2,028,900
	Ambulance attendance - on the spot treatment	85,000	34,300	119,300
	ED Presentations, 64+ yrs	128,800	299,200	428,000
	Mortality	495,230,900	1,153,063,600	1,648,294,500
	TOTAL HEALTH	496,890,000	1,153,980,700	1,650,870,700
Transport	Delayed travel time	3,230,200	7,259,500	10,489,700
Energy	Energy demand from temperature > 30 degrees	Not assessed as heatwave impact	99,251,500	99,251,500
	Reduced energy demand on cold days (benefit)	Not applicable		
	HV Faults	989,000	2,185,800	3,174,800
	LV Faults	1,939,800	4,821,000	6,760,800
	TOTAL ENERGY	2,928,800	106,258,300	109,187,100
Anti-Social Behaviour	Cost of assault	25,707,700	76,487,300	102,195,000
Trees and animals	Irrigation	413,800	984,100	1,397,900
	Heat-related tree death	Not assessed as heatwave impact	38,052,500	38,052,500
	TOTAL TREES AND ANIMALS	413,800	39,036,600	39,450,400
TOTAL IMPACTS		***529,170,500***	***1,383,022,400***	***1,912,192,900***

Table 51 Summary of economic assessment of heat impacts attributable to the UHI Effect – A1FI Scenario

Catgeory	Impact	UHI Attributable Heat Impacts (Present Values discounted @ 3 %)		
		Heatwave costs ($)	Single hot day costs ($)	Total heat costs ($)
Health	Ambulance attendance - with transport	450,700	68,900	519,600
	Ambulance attendance - on the spot treatment	26,500	4,100	30,600
	ED Presentations, 64+ yrs	40,200	35,300	75,500
	Mortality	154,438,400	136,201,700	290,640,100
	TOTAL HEALTH	154,955,800	136,310,000	291,265,800
Transport	Delayed travel time	941,900	1,109,900	2,051,800
Energy	Energy demand from temperature > 30 degrees	Not assessed as heatwave impact	96,619,900	96,619,900
	Reduced energy demand on cold days (benefit)	Not assessed as heatwave impact	- 110,159,700	- 110,159,700
	HV Faults	251,200	160,200	411,400
	LV Faults	471,800	262,500	734,300
	TOTAL ENERGY	723,000	- 13,117,100	- 12,394,100
Anti-Social Behaviour	Cost of assault	8,688,000	8,837,600	17,525,600
Trees and animals	Irrigation	984,100	118,100	1,102,200
	Heat-related tree death	Not assessed as heatwave impact	3,805,200	3,805,200
	TOTAL TREES AND ANIMALS	984,100	3,923,300	4,907,400
TOTAL IMPACTS		***166,292,800***	***137,063,700***	***303,356,500***

Appendix C

Electricity pricing

Appendix C Electricity pricing

The following information is provided to expand on how current electricity prices factor in future infrastructure costs, as mentioned in Section 5.5.2.

Retail electricity prices (i.e. prices for households and small businesses) are highly regulated in Australia. The final retail price enables the electricity retailers to recover three sets of cost:

- Wholesale electricity costs: costs associated with buying electricity from the wholesale market
- Network costs: costs associated transmitting and distributing electricity from generators to end-users
- Retail operation costs: costs such as marketing and billing and a retail margin.

The weight given to each component in overall retail prices varies by individual retailers, but on average the wholesale and network cost components each account for approximately 45% of the total retail price, while retail costs and margins make up the remaining 10%.

7.1 Wholesale electricity costs

The National Energy Market is the wholesale marker from which electricity is purchased by electricity retailers (except in Western Australia and the Northern Territory). Mediated by the Australian Electricity Market Operator (AEMO), generators and retailors engage in an open-bid-offer process every 5 minutes to determine the equilibrium price, where supply equals to demand.

Because wholesale prices are set by the market, but retail prices are regulated for the next 12 to 36 months, state regulators must estimate the cost of wholesale electricity that will be faced. This is typically achieved by estimating both the long run marginal cost (LRMC) of generation, and an expected 'market price' for electricity.

LRMC is based on the price that would be charged by a theoretical system of generators which is designed to meet the retailer's energy requirements at the least cost into the future. That is, the mix of generators that is selected does not necessarily reflect the actual mix of generators in the market – it will vary as relative fuel costs change and some forms of power generation become relatively cheaper. Thus the LRMC is affected by changes in fuel costs, projected changes in technology, improvements in operational efficiency and changes in the cost of building new generators.

The approach to determining the 'market price' that retailers are expected to face varies slightly by state, but generally involves consideration of expected spot prices and possible contract arrangements. The process is complicated, but it essentially tries to determine the total cost an 'efficient' retailer would face in sourcing their electricity requirements If they used an optimal combination of purchasing from the spot market and using contracts to hedge against large price movements.

7.2 Network costs

Network costs can refer to two specific types of costs in procuring electricity: transmission network cost and distribution network cost.

Transmission network refers to the upstream and high-voltage power line network between generators and the next level distributors. Transmission networks are usually linked across state borders.

Distribution network comprises lower-voltage power lines, providing the link from the transmission network to the end customer.

Transmission charges make up about 10% of retail prices, while distribution charges make up about 35% to 50%. Both are very capital intensive and typically one transmission and distribution network service a given area, giving rise to geographical monopolies. As such, governments impose significant regulation on these networks.

The transmission and distribution networks in Victoria are regulated by the Australian Energy Regulator (AER). The AER sets 5-year revenue caps based on expected costs during that period. The regulatory process takes around 13 months.

The AER's decision is based on the amount of revenue that would reasonably be required to recover a set of costs. These costs are:

- Operational and maintenance expenditure, such as wages and rents

- A return on capital (which is affected by capital expenditure)
- Asset depreciation costs
- Tax liabilities

Although it varies by network, the return on capital appears to be the largest component for both transmission and distribution network.