CRC for
Water Sensitive Cities

Determine the microclimate influence of harvesting solutions and Water Sensitive Urban Design at the micro-scale

Green cities and microclimate

An Australian Government Initiative

CRC AUSTRALIA

Project B3.1: Green Cities and Microclimate – Interim Report 2

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Executive Summary

Water Sensitive Urban Design (WSUD) has the potential to provide cooling effects across the urban landscape through both evapotranspiration and shading. A review of the literature has identified that there is capacity to intentionally modify urban climates by reintegrating stormwater back into the urban landscape through WSUD. However, there is little empirical evidence demonstrating the climatic benefits of WSUD and it has been identified that more research is needed to quantify the intensity of cooling and improvements to human thermal comfort from WSUD features.

Project B3.1 of the CRC for Water Sensitive Cities aims to quantify some of the effects of WSUD on urban climate. This interim report provides information on **the data gathering from household (micro) scale field systems** that support this aim. A number of household scale research projects are currently underway that attempt to improve our understanding of how WSUD acts to modify the microclimate, and what this may mean for human thermal comfort.

Each household scale project is identified and described broadly in terms of the main aims and the methodological approach. At this interim stage of the research, results and conclusions are emerging and beginning to identify the interactions between WSUD and microclimate. Information is also emerging concerning the design of WSUD and stormwater harvesting systems for meeting Climate Sensitive Urban Design objectives.

Overall, this household scale research aims to assess the effectiveness of different WSUD approaches for urban cooling – particularly at the micro-scale. In combination with our neighbourhood-to-city scale research (including observations, remote sensing and climate modelling), outcomes will help to provide guidance on optimal implementation approaches of WSUD to maximise urban cooling and improve human thermal comfort under summertime conditions.

While this report has been developed for Project B3.1, some research projects are undertaken in collaboration with other parts of the CRC program.

Project 1: The thermal benefits of urban street trees*

The City of Melbourne has approximately 22,000 street trees with an estimated value of $250 million. The overall age distribution of the City's tree stock is skewed to older trees and together with the effects of the drought and extreme temperature events, many of the existing trees are in distress. It is estimated that there will be >30% loss of tree population during the next 10 years. This research project aims to quantify the micro-climatic benefits of trees at the street scale. This is being done by monitoring temperature and human thermal comfort in selected streets in within the boundaries of the City of Melbourne. This will help identify best practice planting of the future urban forest to provide maximum comfort and cooling in the urban environment, and guide investment in protecting existing tree stocks.

In this project, 20 microclimate monitoring stations were installed in three streets in the City of Melbourne: Bourke St, CBD; Gipps St (non-treed), East Melbourne; and George St (treed), East Melbourne. The aim is twofold: 1) to monitor the influence of individual trees within a single, dense urban canyon; and 2) to compare the urban canyon environment of a treed and non-treed street. Microclimate monitoring stations measure air temperatures (T_a), humidity, wind speed and mean radiant temperature. The combination of these measures allows us to calculate Human Thermal Comfort (HTC) using a chosen index such as Physiological Equivalent Temperature (PET).

Urban micro-climate monitoring station in Gipps St, East Melbourne

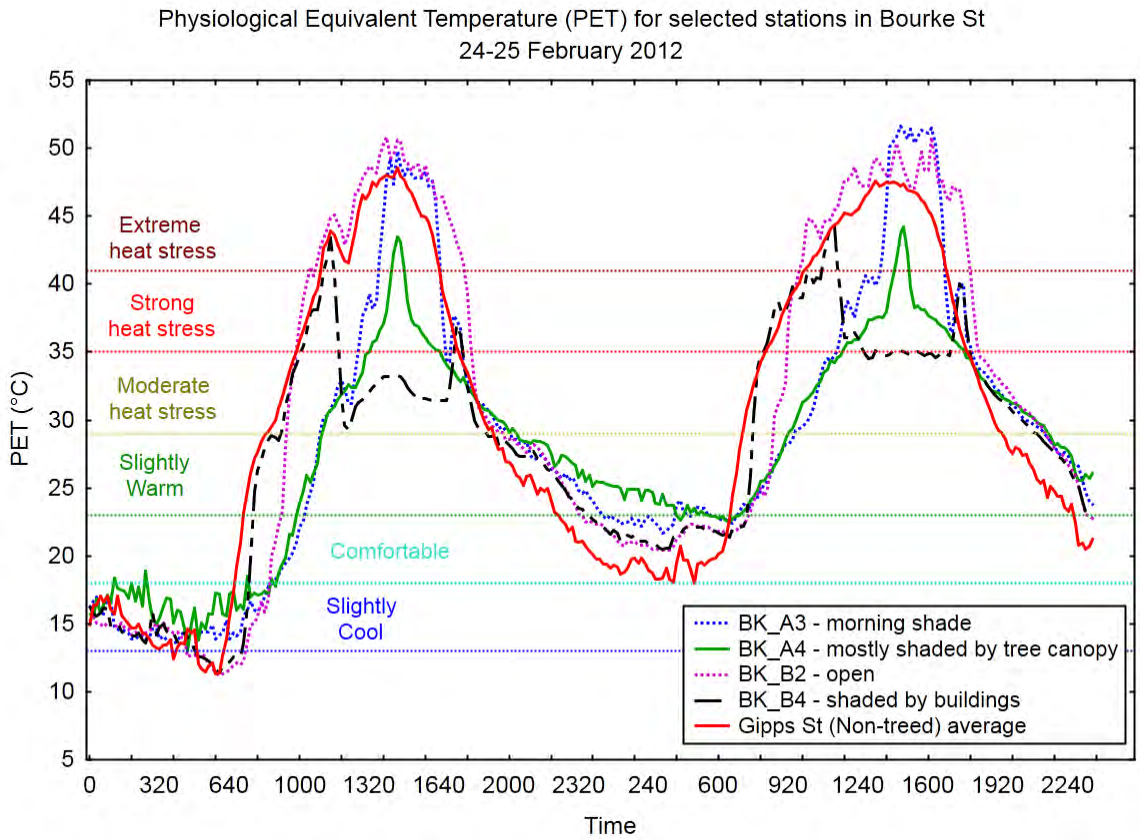
Bourke St (upper) in the Melbourne CBD, Gipps St (middle-treed) and George St (lower – non-treed) in East Melbourne and location of micro-climate monitoring stations in the open (red) and under the shaded by the tree canopy (blue)

Initial findings of this research highlight the benefit of individual street trees on HTC. Shading from the tree canopy reduced Mean Radiant Temperature (T_{MRT}) and leads to lower peak daytime PET. Under hot, sunny daytime conditions during an Extreme Heat Event (EHE) (24-25 Feb 2012), tree shading can lower PET by around 12-14 °C altering HTC from "extreme heat stress" to "strong heat stress". Building shade is also

effective at lowering PET. At night, the tree canopy can elevate PET due to trapping of radiant energy below the canopy and reduced wind speeds, but the overall net benefit of trees under hot, sunny conditions is positive.

Comparing the mean T_a of the three street canyon environments, street trees did not have an obvious influence. Results showed that the street with trees was 0.2 – 0.6°C cooler during the day than the street with little vegetation under warm northerly conditions in summer. Results also showed that at night, the dense street canyon environment (Bourke St) with a large 3-dimensional impervious surface cover overwhelmed any influence of the tree canopy. During an EHE (24-25 Feb 2012), the mean T_a was 4.8°C higher than the more open streets in East Melbourne.

This research highlights that processes influencing T_a are extremely complex at the micro-scale and it is difficult to isolate the influence of trees from the influence of canyon geometry. Microclimates are extremely complex and highly variable both spatially and temporally, driven by differences in solar access, adjacent surface characteristics, geometry, turbulence and prevailing wind flows. Further research is needed concerning statistical analysis of the data. Monitoring continued throughout the 2012-13 summer in the East Melbourne streets.



Physiological Equivalent Temperature on 24- 25 February 2012 for selected stations in Bourke St compared with the mean PET for Gipps St (non-Treed).

*** This project is supported and jointly funded by the City of Melbourne**

Project 2:
Microclimate assessment of tree cooling processes*

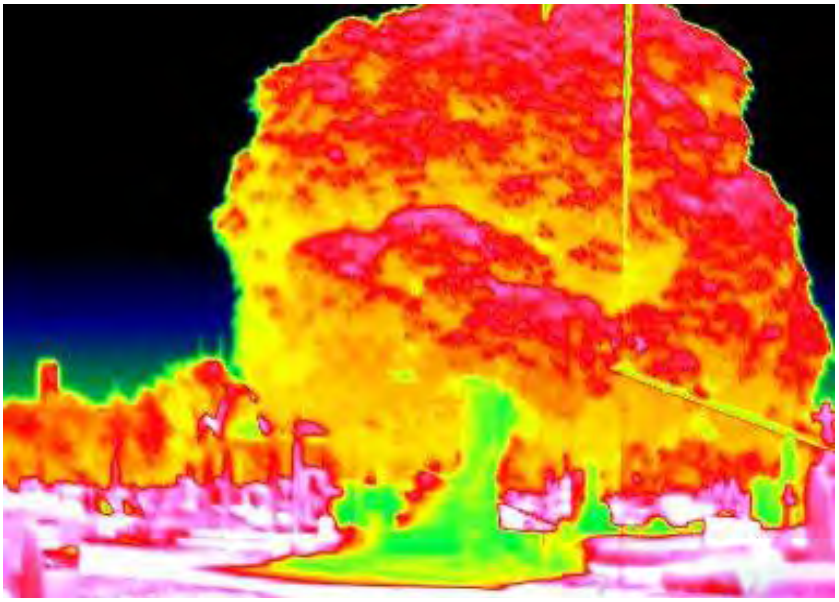
This project is a complement to PROJECT 1, and aims to understand in greater detail the cooling processes that occur inside urban tree canopies in the urban environment. There is evidence that an isolated stand/line of trees with a closed or semi-closed canopy within a warm, dry urban environment will, as a result of energy budget processes operating throughout the vegetated system, develop an internal temperature profile that under ideal conditions can drive a micro-scale air circulation. Whilst the crown area of the tree is an area of radiative heating, the trunk zone within and below the canopy remains relatively cool, causing air to subside in the trunk zone and diverge at footpath level. Conceptually, the circulation would then close by air rising over the heated surfaces adjacent to the trees.

The core element of the project involved instrumenting the tree stand from ground level to above the crown using iButton temperature/humidity sensors mounted on light aluminium masts. Five masts are used to collect a cross section of temperature/humidity through the tree canopy – 10 per mast. An isolated tree (Queensland Brush Box - *Lophostemon confertus*) was selected within the Melbourne General Cemetery – a location that captures the kind of intense urban environment trees can be exposed to (hot surrounding impervious surfaces). Radiation observations were also conducted both above and below the tree canopy, and thermal images were taken throughout the day of the tree canopy and surrounding impervious surfaces. Instrumentation was installed for a two-week period and an intense heating period was captured during this time (24 February 2012).

Monitoring of an isolated tree surrounded by hard, impervious surfaces.

Results highlight that the area of shade produced by the tree canopy drastically reduces the surface temperature (T_{surf}) of the ground surface. The tree canopy absorbs and reflects incoming solar radiation, and in combination with reduced T_{surf} would result in a reduction of T_{MRT}. At around 3pm - 4pm as the surface temperature of the canopy (i.e. leaf temperature) increased, and high vapour pressure deficits during the EHE would likely lead to the closure of the leaf stomata to restrict water loss and a decrease in transpiration. This highlights the important controls of vegetation on urban climate, and the need to ensure sufficient water is available to the root zone to support tree health during extreme heat.

Further research is needed concerning the collection and calibration of air temperature sensors and correction of data in order to accurately quantify T_a inside and outside the tree canopies to provide a measure of absolute temperature differences.



Infrared thermal image of the isolated tree at 2pm on 24 February 2012

*** This project is supported and jointly funded by the City of Melbourne**

Project 3:
Comparison of thermal benefits of green and white roofs

A mix of approaches is likely to be needed to help mitigate the urban heat island and reduce exposure to warm urban temperatures. Green (vegetated) roofs and white roofs are regularly suggested as effective rooftop treatments to support urban cooling. The UHI phenomenon is often most pronounced at night, as heat stored in street canyon floors, walls and building rooftops is slowly released at night, warming urban areas. Green roofs provide an insulating layer to the rooftop so heat transfer into buildings is reduced, while white roofs have a high surface albedo (reflectance) and so reflect solar energy and limit heat transfer and storage in the rooftop. In terms of mitigating the UHI, local councils and residents with limited financial resources are likely to be interested in achieving maximum cooling effects for least cost, and maximising benefits for internal building energy use.

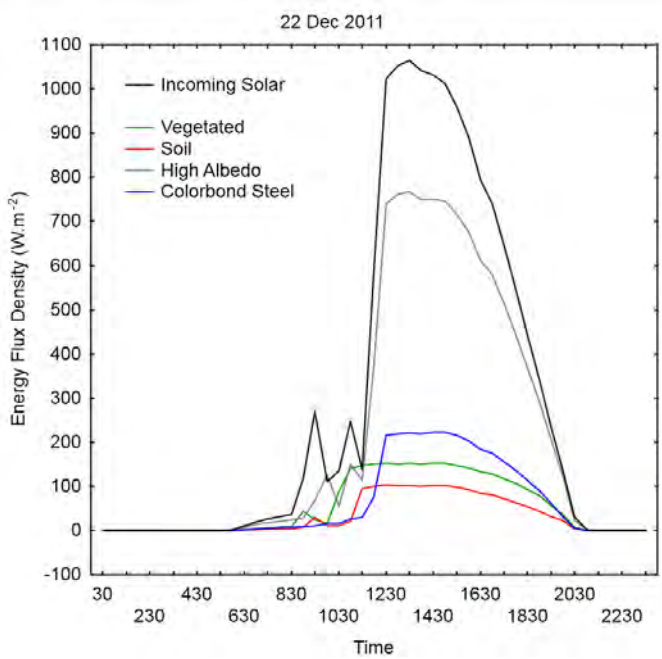
This study compares the effectiveness of green and white roofs in reducing heat transfer through an experimental rooftop and the radiative effects of different rooftop treatments. Four experimental rooftop rigs were used in this study: a conventional rooftop with Colorbond steel roofing; a conventional rooftop with a white elastomeric ceramic coating; a rooftop with an extensive vegetated roof (15 cm soil substrate and succulent vegetation); a rooftop with just the soil substrate layer. Each experimental roof rig was instrumented for the complete radiation budget, surface temperature, soil temperature, soil heat flux, albedo and soil moisture. Standard meteorological variables were also measured. Each rooftop rig also had a roof cavity airspace underneath which was instrumented for temperature. These data provide a good basis for comparing different rooftop treatments. Data from these experimental rooftop rigs will be complemented by data from an actual green roof constructed on the Monash City Council civic building.

The green roof experimental rig

The extensive green roof treatment (upper) and the white elastomeric insulating ceramic coating (lower)

Measurements were conducted over the 2011-12 summer. Here, data from a single clear sunny day is presented (22 December 2011). Comparing the albedo of each of the roof treatments, the roof with the white elastomeric ceramic coating drastically increased the albedo. As a result, this rooftop had a much lower amount of net radiative energy available at the roof surface for transfer into the roof cavity below. The soil roof had a low albedo due to the dark soil colour, while the addition of vegetation served to slightly increase the albedo of the vegetated roof compared to just a bare soil roof.

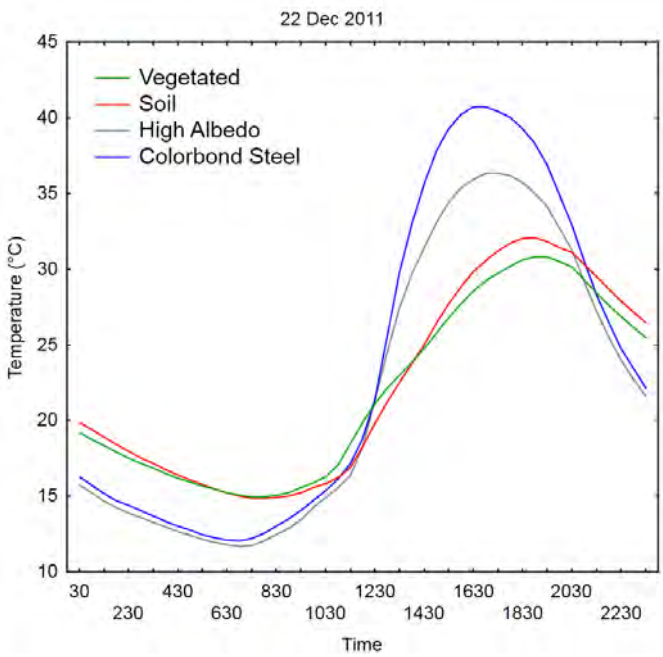
Comparing the air temperature of the roof cavity airspace underneath each rooftop, the insulating effect of the soil and vegetated roof treatments was clear, reducing temperatures during the day, while keeping the cavity airspace warm at night compared to the un-insulated Colorbond steel roof. The effect of the high albedo of the white painted roof leads to a reduction in the air temperature compared to the Colorbond steel roof, but the cavity airspace is still warmer than the vegetated and soil rooftop treatments.



Relected solar radiation of each rooftop treatment on 22 December 2011

Further work is needed in analysing the entire summertime dataset and to draw out the full implications of this work, along with the effects of soil moisture. From initial findings, the benefits of green roofs could be enhanced with a lighter coloured substrate, or a layer of white pebbles on the rooftop to increase the surface albedo.

While there is a clear benefit of the vegetated roof on the cavity airspace, the influence of each roof treatment on the adjacent roof microclimate is more complex and requires an understanding of the roof surface properties on atmospheric heating. Further work will combine data from Projects 3 and 4 to determine overall impacts of different rooftop treatments on atmospheric heating.



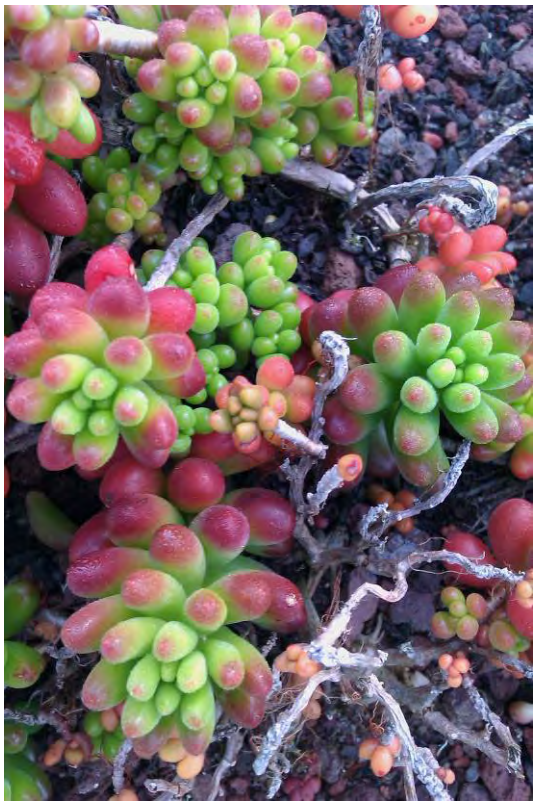
Air temperatures of the cavity airspace for each experimental rooftop treatment

Project 4:
Evapotranspiration from an experimental green roof

Evapotranspiration (Q_E) from green roofs is often cited as a key mechanism for cooling to support Urban Heat Island mitigation. In contrast with impervious urban surfaces, green roofs permit infiltration and store water in the pervious soil layer. Research has attempted to quantify daily rates of evapotranspiration in studies of green roof water balances, and either estimate evapotranspiration as a residual of the water balance, or by weighing lysimeters. However, daily estimates of evapotranspiration only tell part of the story, and as microclimates evolve during the day, the role of evapotranspiration in controlling these climates is required. Furthermore, extensive green roofs commonly have thin, coarse substrate soils that support succulent vegetation types that may not heavily promote evaporative cooling.

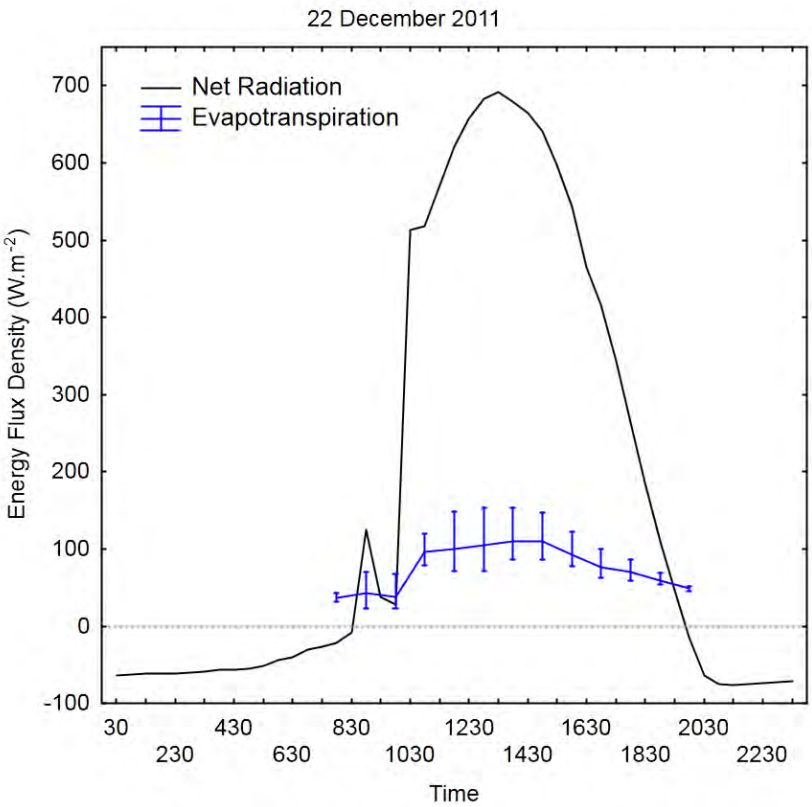
The aim of this study is to quantify diurnal variations in evapotranspiration and the surface energy balance of a green roof, to understand the role of evaporative cooling on rooftop microclimates. This study uses a chamber approach, whereby a clear chamber is placed on the roof over a short period. Using an infrared gas analyser, we can measure the rate of increase of water molecules in the chamber and then calculate the flux of evapotranspiration. In combination with the radiative and conductive measures being undertaken on the green roof from Project 3, we can calculate the surface energy balance, which is fundamental to the development of urban climates. Chamber measurements are taken under a variety of conditions, along with soil moisture and meteorological data to understand parameters influencing evapotranspiration. The contribution to atmospheric heating from the green roof will be compared to a conventional roof to determine its effectiveness in cooling the rooftop microclimate.

The manual chamber used for measuring rates of evapotranspiration



Sedum Rubrotinctum – the succulent vegetation type on the experimental green roof

Evapotranspiration (latent heat flux) was observed using chamber measurements on seven individual days, with observations taken hourly from at least 8am to 8pm. All of these days were warm, clear sunny days; these are days when the cooling effect of green roofs is needed. An example of the Q_E data is presented here for the vegetated experimental roof on 22 December 2011, when the maximum temperature was 29.2 °C. On this occasion, Q_E was low, with values peaking around an average of 100 $W.m^{-2}$, but with individual values as high as 153 $W.m^{-2}$. Only a small proportion of available energy at the surface of the vegetated experimental roof is used in evapotranspiration.



Net radiation and evapotranspiration of the vegetated experimental roof on 22 December 2011. Bars denote range of observations

Data analysis is ongoing in this project, but initial findings suggest that while green roofs are commonly cited as an UHI mitigation measure, unless moisture is evaporating and the vegetation actively transpiring, rates of evapotranspiration can be low, as in this example. The thin substrate may not store large amounts of water, and the succulent vegetation may be conserving water, limiting Q_E. To investigate this further, an irrigation experiment was conducted and Q_E observations taken over three of the total 7 days observed. Q_E was much higher on these days, but more analysis is needed to truly understand all the mechanisms involved here. It is also important to note that in this study, the experimental green roof is a long established green roof that has not been irrigated. Vegetation was not dense like on a newly established green roof, and vegetation health improved throughout the summer following fertilisation.

Further work will involve the investigation of the surface energy balance from the data collected and the contribution of different rooftop treatments to atmospheric heating, in combination with data from Project 3.

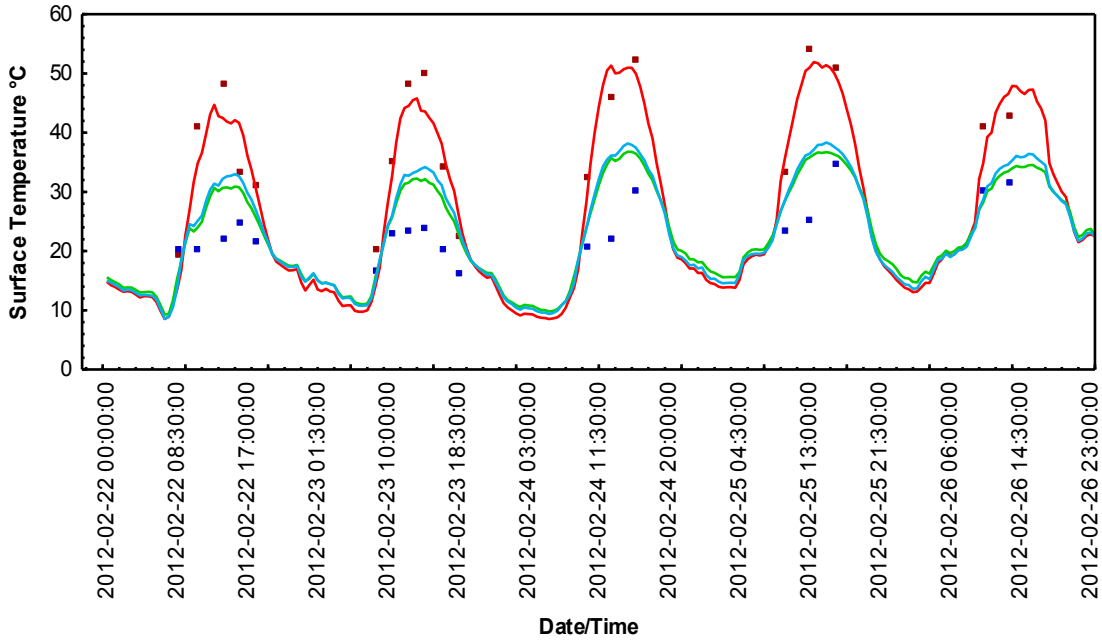
Project 5: Footscray Primary School irrigation study

Studies have found that urban green space can play an important role in microclimate adjustment, decreasing temperature, increasing humidity and providing an overall improvement in human thermal comfort on hot summer days. Parks can provide cool refuge islands among heated housing (Park Cool Island [PCI]). Vegetation, by supporting higher rates of evapotranspiration, can reduce the energy available for atmospheric heating and as a result, also act as a natural cooling mechanism. In the event of a day with extremely high temperatures, maximising cooling from urban green spaces is particularly important to minimise the heat stress of urban occupants and reduce mortality rates.

The aim of this study was to analyse the effects of irrigation of an urban park on local and downwind climate and its control of PCI intensity. In this study, the oval at Footscray Primary School was irrigated prior to a warm sunny period. A range of instrumentation was installed on the oval to monitor surface temperature, soil moisture, and evapotranspiration rates using chambers. A section of the oval was kept dry for a comparison. Over 50 iButton temperature/humidity sensors were distributed throughout the surrounding area to monitor the PCI. Also, a row of aluminium masts was installed downwind of the irrigated area, with five iButtons on each mast in an attempt to observe downwind cooling effects. Instrumentation was installed for a three-week period.

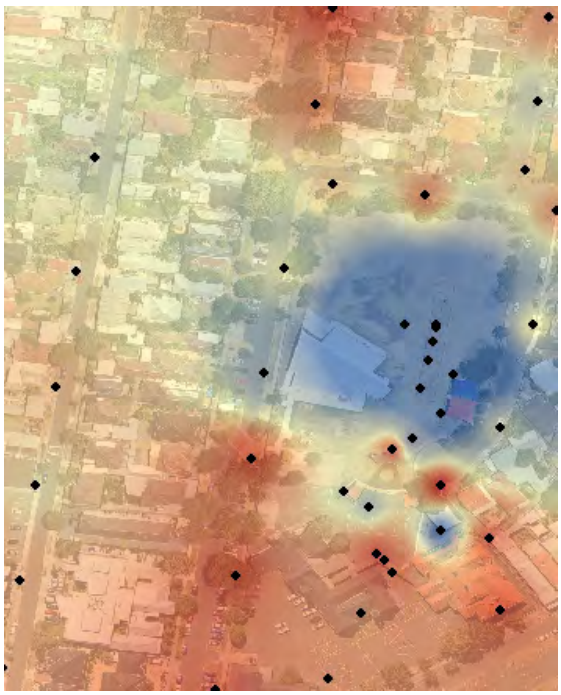
The location of the oval at Footscray P.S. and surrounding iButton sensors (upper-left), chambers for measuring evapotranspiration from the irrigation event (lower-left), and the masts to monitor downwind cooling effects (upper-right)

The study was undertaken from 8 February 2012 to 26 February 2012. During this time, two irrigation events were undertaken on 14 and 22 February. Following the irrigation events, obviously there was an increase in soil moisture for the irrigated area compared to the control dry zone. In conjunction with this, there was a clear reduction in surface temperature of the irrigated area as a result of surface evaporative cooling, and changes to soil thermal properties. This evaporative cooling effect was observed using chamber observations, and showed that following irrigation, evapotranspiration increased and after the second irrigation event, evapotranspiration was as much as three times higher than the dry zone.



Surface temperature of the irrigated (blue lines) and dry zones (red line) of the park using automatic (solid lines) and manual (dots) instrumentation following the 2nd irrigation event (22 Feb 2012)

Despite the clear effect of irrigation at the surface, the influence of the irrigation event on air temperatures was more complicated, and is difficult to capture in field-based observations. The PCI was evident during the night (see figure) both before and after the irrigation event as the green space cools rapidly after sunset compared to the surrounding urban landscape. During the day, the park actually acted as a Park Heat Island due to the dry hard surface, even after irrigation. Only immediately following the 2nd irrigation event did the park act as a cool island during the day. Further exploration of the data may reveal additional findings.



PCI at 1am on 24 February 2012

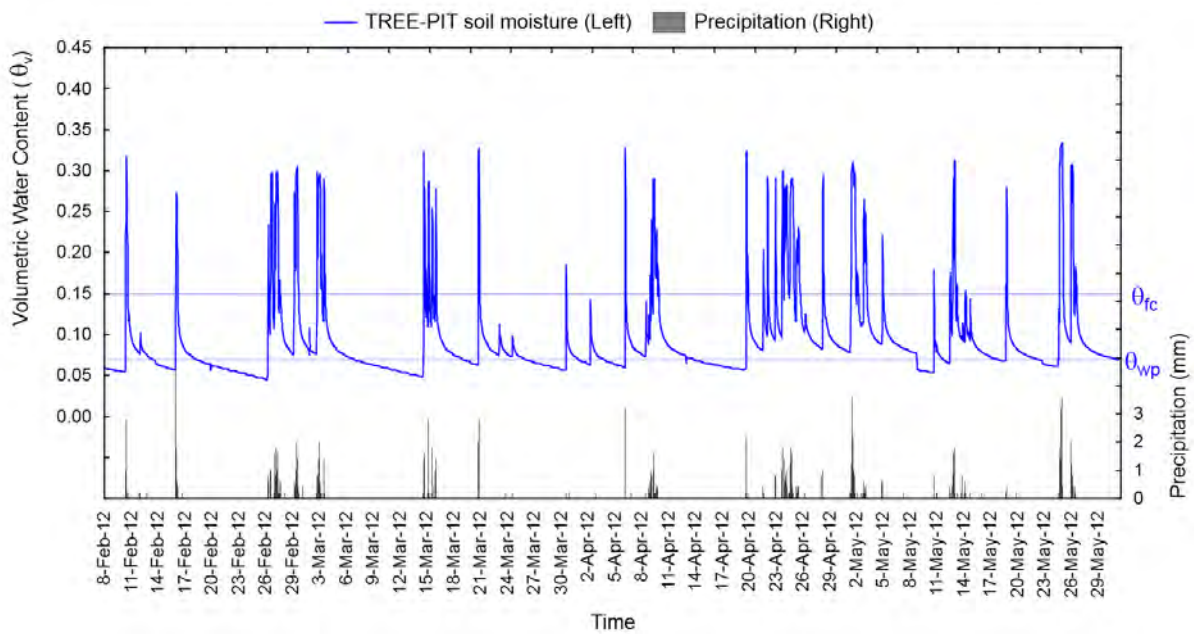
Project 6:
Tree Response to Urban Environmental Conditions and Water Availability

Studies of future climate change on forest stands suggest that trees will face significant pressures of heat stress and drought. Urban trees in many ways already experience these pressures from high heat and radiative loads and low water availability compared to rural trees, along with elevated CO_2 concentrations. Low water availability to the tree root system and higher levels of heat stress due to the UHI, can compromise tree function and may limit the effectiveness of a tree in providing cooling benefits. Tree-pits allow stormwater to flow into the root zone for trees to draw on, and act as a conduit for water loss to the air. However, there is no research on the effectiveness of a tree-pit in meeting the water needs of trees, to facilitate ongoing transpiration and to assist the tree to cope during periods of heat stress.

There are two main aims in this study: 1) to understand the microclimate experience of urban trees; and 2) to understand the tree response to varying environmental conditions within a complex street canyon environment. This study is *not* aimed at understanding the cooling effect of trees themselves. This study also seeks to understand if the tree pits play any role in influencing tree response and monitors trees in Smith St, Collingwood. This study draws on micro-scale observations of temperature, humidity, soil moisture, solar radiation and terrestrial radiation, along with observations of street CO_2 concentrations. In addition, leaf-scale observations of photosynthesis, stomatal conductance and leaf temperature (amongst many other things) are monitored for tree response.

Smith St tree monitoring including leaf scale observations (lower-left) and soil moisture (lower-right)

One expectation of WSUD implementation is that it will increase water availability to the root zone and enhance tree health. Soil moisture was monitored in four tree pits from 8 February 2012 to 15 June 2012. Soil moisture increased in the WSUD tree-pits rapidly during rain events and the soil became saturated. However, the sandy soil of the tree pits meant that infiltration was high, and so while soil moisture was high at times, it also dried out rapidly. This is the functioning required to meet stormwater management objectives, but it may not be ideal for tree health. Street trees will generally require soil moisture levels between field capacity (θ_{fc}) and wilting point (θ_{wp}) for optimal growth conditions.



Average soil moisture in the Smith St tree pits from 8 Feb 2012 to 29 May 2012

The microclimate data collected suggests that street trees experience some interesting anthropogenic influences. Shading from buildings reduced the photoperiods of the trees, shortening the diurnal period for carbon uptake. High morning and afternoon radiation loads were observed from reflected shortwave radiation off walls. Very high CO_2 concentrations were also observed at times, with concentrations observed as high as 600 ppm during the early morning traffic peak. The microclimate of the street canyon was also warmer and drier than conditions observed at the nearby BoM CBD weather station.

These conditions and soil moisture regimes will influence the response of the trees (*Eucalyptus Olivacea* and *Olea Europaea*) in the tree-pits. Ongoing work will include finalisation of the data concerning the tree response to urban environmental conditions. This project has collected an excellent dataset that could be used for validation of tree-pit parameterisations in urban climate models and Single Plant Ecosystem (SPE) models.

Project 7:
Assessment of evapotranspiration from rain gardens in Little Stringybark Creek

Stormwater impacts on the health of urban streams are increasingly recognised worldwide. Alternative stormwater management techniques to the traditional "pit and pipe" network (e.g. bio-retention systems, or "rain gardens") are being developed, having effects on both the water quality and the flow regime of receiving waters. The Little Stringybark Creek project, about 40 km from Melbourne, is amongst the first catchment-scale experiments studying the effects of an intensive implementation of rain gardens on stream health.

One question addressed by the project relates to the effects of bio-retention systems on the evapotranspiration (ET) flux of the catchment. Increased evapotranspiration has the advantage of both reducing stormwater runoff from urban areas, and helping to reduce the urban heat island effect. Therefore, there is a need to better understand the total evapotranspiration from rain gardens, which likely depends on the surrounding vegetation and soil type. It is postulated that not only the rain garden itself augments evapotranspiration, but it also enhances surrounding soil moisture, which in turn modifies the evapotranspiration flux from a larger area.

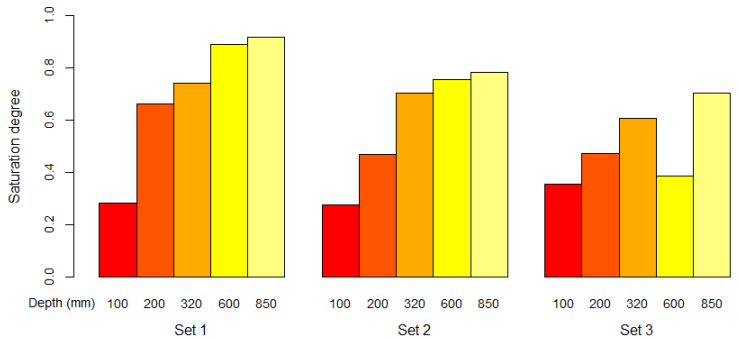
To explore this question, two rain gardens have been monitored in the Little Stringybark Creek catchment. Soil moisture around the rain garden and relevant meteorological data have been recorded for several months, and direct evapotranspiration measurements were performed with flux chambers. Chambers were installed along a transect at increasing distance from the rain garden. Comparing the soil moisture and the evapotranspiration rates measured next to the rain garden and further away – at a location unaffected by the rain garden – allows the assessment of the total water budget of the system. If the area next to the rain garden yields higher evapotranspiration, then the contribution of these systems will prove to be larger than that provided by their sole footprint.

One monitored raingarden in Little Stringybark Creek catchment

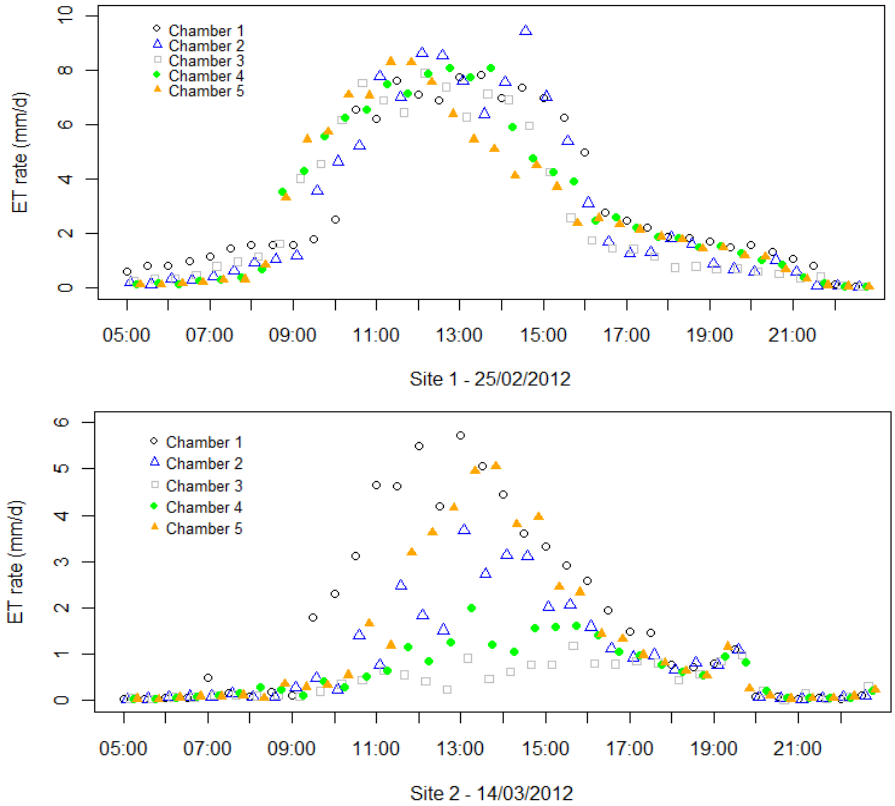
The evapotranspiration chambers on a transect starting next to the raingarden

The data collected in February and March 2012 confirmed that during summer, the rain garden had significantly increased the surrounding soil moisture ("Set 1" in figure A below), compared to a reference point ("Set 3"). However, ET measurements from flux chambers installed on Site 1 were not significantly different from each other (figure B). This suggests that the rain garden did not increase the ET rates of its surrounding area. We hypothesize that the moisture deficit at the reference point was too small to result in a plant water stress.

On Site 2, ET values from the chambers were more variable, but did not follow the expected gradient of soil moisture, away from the rain garden. Rather, the ET measurements seemed correlated to the surrounding vegetation characteristics, again suggesting that the rain garden did not significantly influence ET of the surrounding landscape. As a drier weather period would likely yield more contrasted results, a second measurement campaign was scheduled for February 2013.



A) Saturation degree of soil at different depths (100 mm to 850 mm-deep) for three different locations: Set 1 is close to the raingarden, Set 2 is 3.5 m away, and Set 3 is 9 m away (data for Feb 2012 on Site 1)

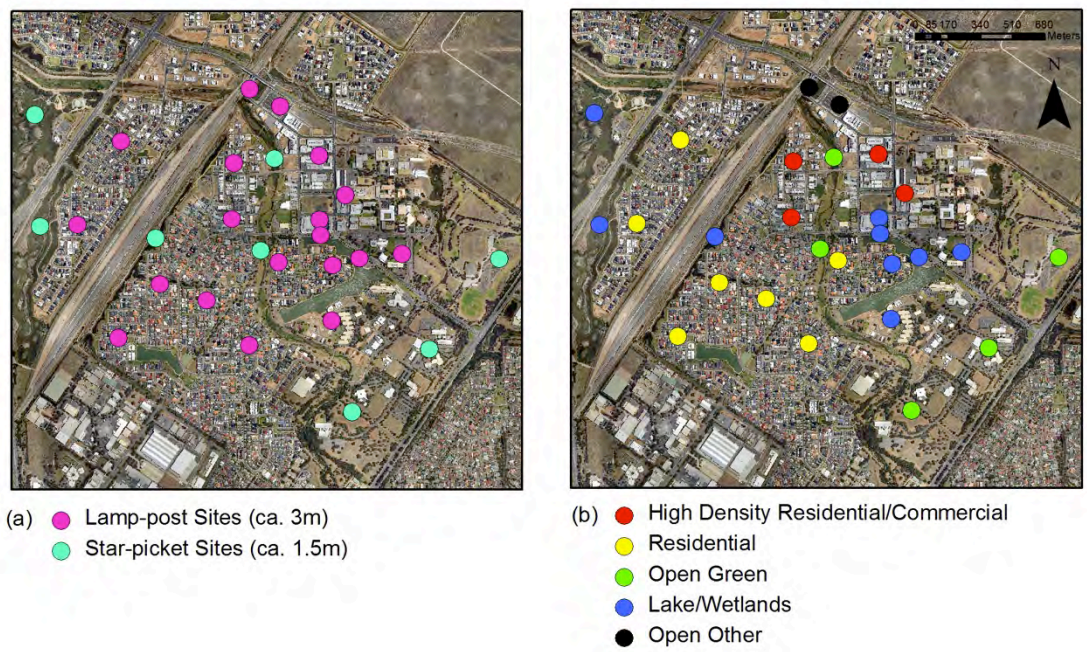


B) Variation in evapotranspiration rate from each chamber for Site 1 and 2. Chambers are ranked relative to their distance to the rain garden (with Chamber 1 being the closest). Total evapotranspiration for Chamber 1 is 2.4 mm/day and 1.3 mm/day, respectively

Project 8:
Microclimate variability across Mawson Lakes

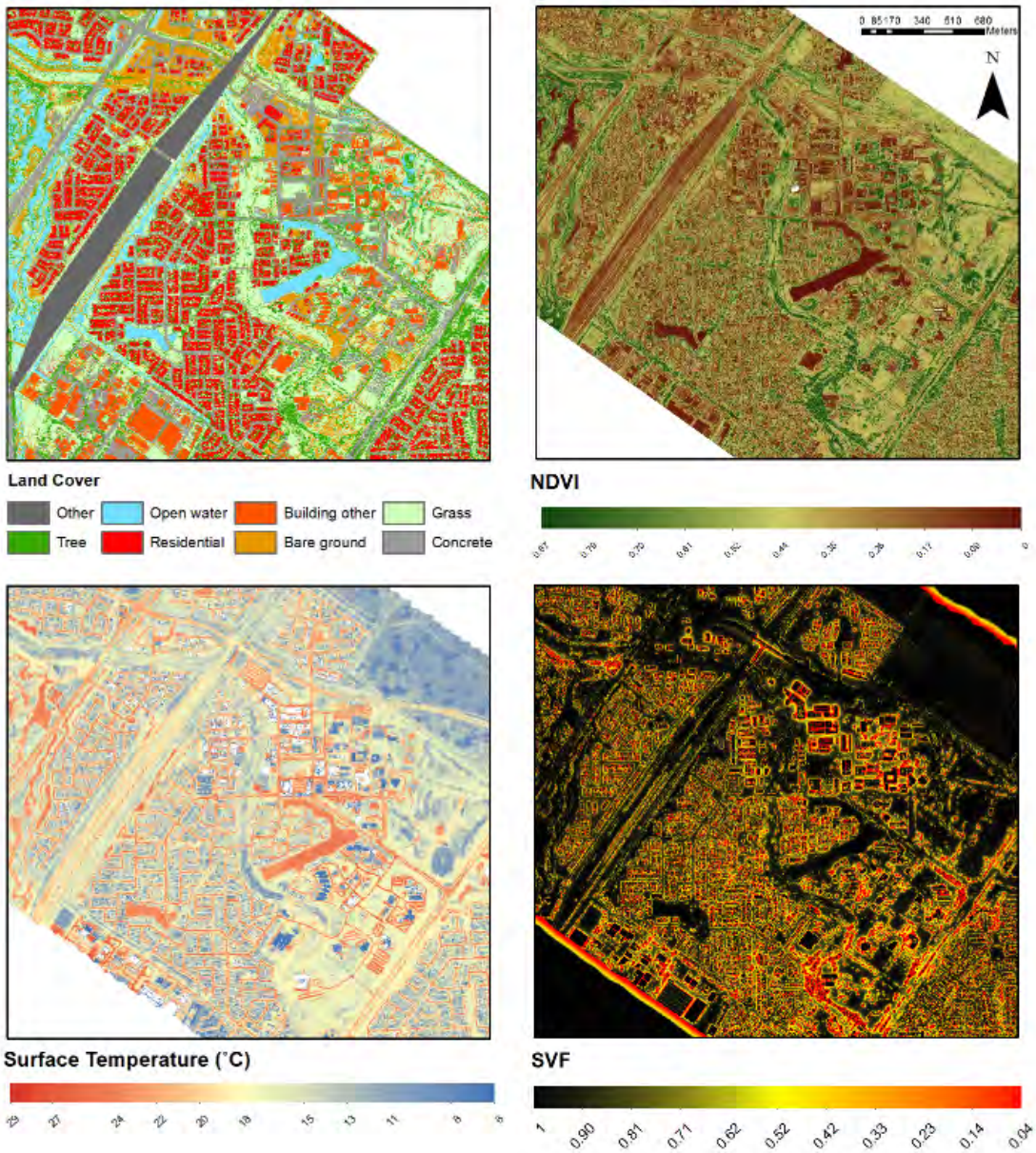
Mawson Lakes is a mixed urban neighbourhood in Adelaide that combines residential and commercial development of different styles and densities. The neighbourhood is characterised by a large system of wetlands and artificial lakes, as well as tracts of irrigated public green space. Recycled water is also available to residents for irrigation. This high level of water available in the landscape is unique for the Adelaide City landscape where surrounding neighbourhoods are characterised by a more water-limited landscape. Open water bodies and heavily irrigated landscapes have the potential to support oasis effects, where warm air is advected over a wet surface, significantly enhancing evapotranspiration. This could provide a means of cooling adjacent urban landscapes.

We undertook a comprehensive microclimate study of the Mawson Lakes environment to understand the influence of landscape water availability and urban design on air temperature and human thermal comfort. In February 2011 a large field campaign was undertaken drawing on multiple research methods. 27 microclimate static stations (automatic weather stations, AWS) were installed across the development to capture the range of intra-urban environments (residential, parkland, etc.).



Static stations deployed in Mawson Lakes: (a.) lamp-post (purple) and metal stake (teal) AWSs and (b.) Land Use (LU) categories

Three high-resolution thermal images were captured (two daytime, one night time). 19 bicycle transects were also conducted to capture high-resolution air temperature variations throughout the development. Aerial imagery and LiDAR data were also collected to characterise the urban landscape. These remotely-sensed data were used to generate the following datasets over the AOI: a land cover (LC) classification, Normalised Difference Vegetation Index (NDVI), surface radiative temperature (T_s), and sky view factor (SVF). These data will ultimately help to understand in detail the key drivers of urban microclimate across a range of landscapes.



Mawson Lakes remote sensing data including: land cover (LC), vegetation cover (NDVI), nighttime surface temperature, and sky view factor (SVF)

During the day, lake and wetland AWSs were cooler than high density, residential, and open green AWSs by 1 °C, on average. Open green AWSs are the coolest at night: on average approximately 0.6 °C cooler than other sites. This analysis begins to reveal the effects of land surface characteristics. However, because there are many factors at play, it remains unclear exactly what variables are contributing to air temperature variability, and to what extent. Multiple regression analysis was undertaken to understand this.

Statistical analysis was used to approximate the size of an idealised footprint for daytime and nocturnal cases (25 m radius circle). This footprint was used to characterise each of the static sites, and multiple regression analysis was conducted. During the day, wind speed (-0.60 °C per 1 ms^{-1}), tree fraction (-0.38 °C per 0.25 tree fraction), SVF (-0.21 °C per 0.25 SVF), and water fraction (-0.35 °C per 0.25 water fraction) were associated with cooling; while pervious fraction (0.53 °C per 0.25 pervious surfaces), building fraction (0.45 °C per 25% building fraction), and concrete fraction (0.40 °C per

25% concrete fraction) have a heating effect.

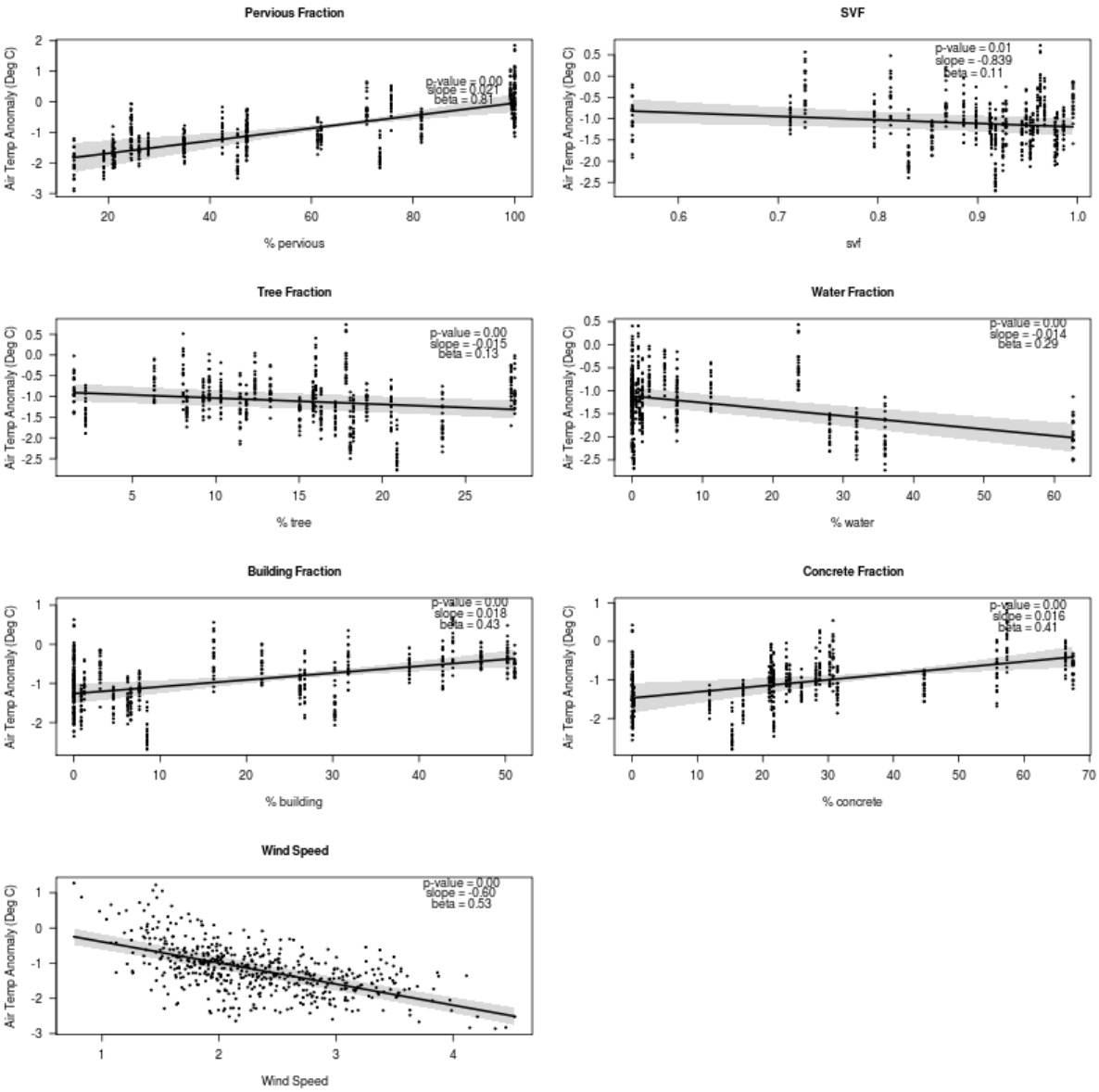
At night, pervious fraction (-0.5 °C per 0.25 pervious fraction), tree fraction (-0.33 °C per 0.25 tree fraction), and wind speed (-0.24 °C per 1 ms^{-1}) were the key variables that control cooling.

At sites with higher wind speeds more mixing of the urban atmosphere occurs. This turbulence transports heat away from the surface into the well-mixed atmosphere. As such, the thermal effects of different surfaces are less apparent. It is this mixing and transport of heat that causes wind speed to be correlated with cooling both day and night.

Trees and water surfaces (lakes and wetlands) have significant cooling effect during the day. This cooling is apparent independent of other influential factors, such as wind speed and SVF. At night, trees and water surfaces have no specific effect. As such, trees and water can provide day-time cooling, and do not cause any notable night-time heating effect.

At night, the rate of cooling is primarily linked to pervious surfaces, which lose stored heat quickly compared to impervious surfaces. However, in this environment, pervious surfaces (excluding trees and water), such as grasses and bare ground, heat up quickly during the day. Grassy sites, without sufficient airflow, trees, or water nearby can become very warm during the heat of the day. A key question is whether these grassy sites would be cooler if irrigated during the day?

Analysis is ongoing in this project to decipher the influence of individual land cover types on micro-scale air temperatures.

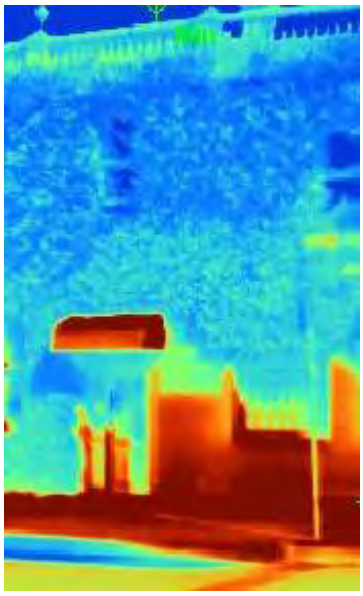


Multiple regression results for daytime average air temperature anomaly vs (a) pervious fraction, (b) SVF, (c) tree fraction, (d) water fraction, (e) building fraction, (f) concrete fraction, and (g) wind speed. Pointwise 95% confidence bands for linear trend included.

Project 9:
Thermal performance of green infrastructure*

Remote sensing is an excellent tool for urban land surface analysis. Airborne thermal remote sensing provides a tool to rapidly capture an excellent spatial picture of urban surface temperatures for a point in time. Previous studies have mapped urban surface temperatures at resolutions of between 1 and 5 metres. This kind of resolution allows for the identification of individual urban surface types, such as buildings, roads, grass and vegetation and an assessment of the thermal performance of different surface types. This study aims to understand the role of green infrastructure and urban geometry in controlling urban surface temperatures. While ongoing research is demonstrating the benefits of green infrastructure for urban cooling, particularly street trees, there is little information on how best to incorporate green infrastructure into the urban landscape to maximise cooling potential.

In collaboration with local councils, two Melbourne municipalities undertook airborne thermal remote sensing in the summer of 2011-12 under hot, clear and calm conditions. We installed 14 ground validation sites over two months across the area to be mapped for validation of the thermal imagery covering a range of surface types (grass, water, concrete, etc.). While the airborne thermal data provides a spatial picture of surface thermal performance, the ground-based sites provide temporal information. Remote sensing was also undertaken using thermography (hand-held thermal camera) to complete the 3D view of urban surface temperatures (e.g. walls) that are not seen from airborne sources. These data were analysed along with air temperature transects and satellite imagery, and compared with high resolution land surface classifications, to relate urban surface and air temperatures to specific land surface features. This information can help guide the implementation of green infrastructure to reduce urban surface temperatures.



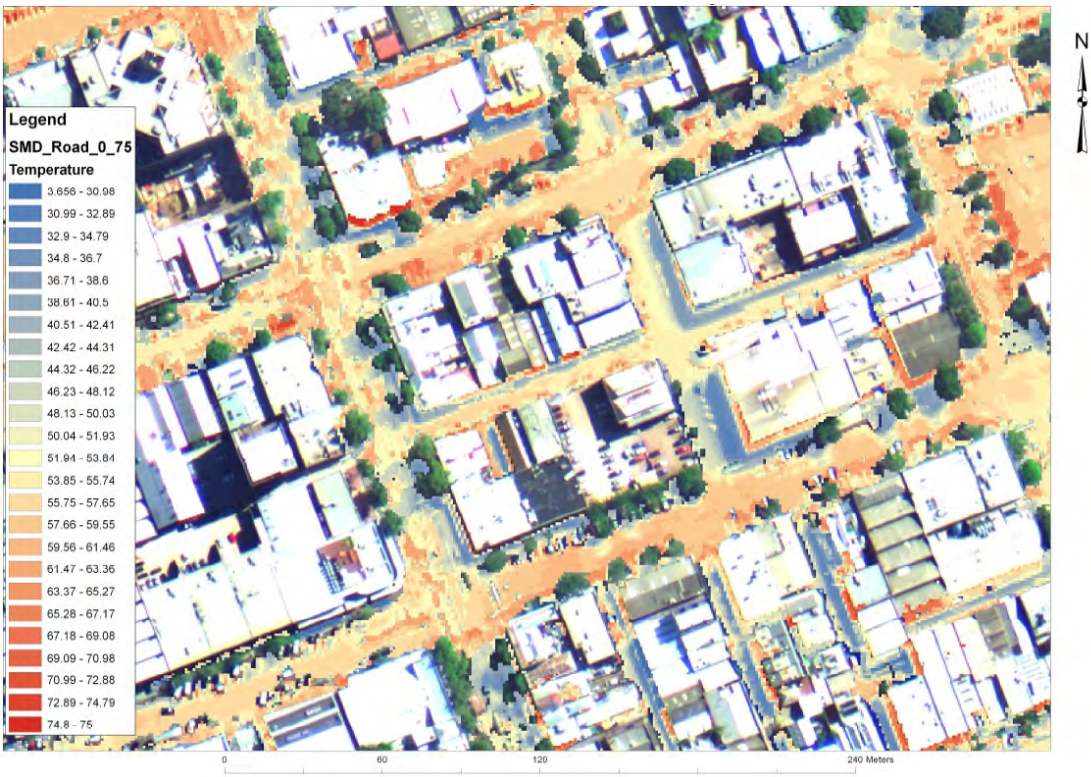
Thermal image of a green facade

Ground based thermography in a street canyon environment.

Ground validation site on a rooftop.

Key findings of the study were that thermal mapping was an excellent communication tool and broadly identified hotspots across the landscape where intervention is needed. High-resolution thermal mapping can provide information on important landscape design features, such as which sides of the street are warmer, the effect of individual tree canopies, or areas where additional irrigation might be needed. Thermal mapping provides information on **surface** temperature, and the study found that surface and air temperature **patterns** were similar, but no clear relationship existed with regards to the **magnitude** of differences in air temperatures.

Vegetation was clearly effective in reducing land surface temperatures, especially during the day. *Under the study conditions*, results suggested that for a 10% increase in total vegetation cover, in general there was around a 1°C reduction in land surface temperature during the day. Trees were most effective in wide streets with low buildings and tree canopies and irrigated grass were the coolest surface types during the day. Analysis showed that irrigation of green space was especially effective at reducing land surface temperatures during the day. This emphasises the point of maximising the cooling efficiency of existing green infrastructure first through irrigation as a priority. Street trees should be prioritised in streets where the height to width ratio is < 0.8.



Daytime thermal image of street surface temperature South Melbourne in the City of Port Phillip on 25 February 2012

Some limitations exist with regards to thermal imagery that reduce its application, and users must be aware of these before proceeding to undertake thermal mapping. These include issues concerning emissivity adjustment of temperature and challenges in collected quality data.

Further work in this project involves the development of a Green Infrastructure Implementation Guide (GIIG) based on information from the thermal mapping exercise and literature to provide advice on the strategic placement of vegetation to maximise surface cooling.

*** This project is funded by the Victorian Centre for Climate Change Adaptation Research (VCCCAR) and is a joint project with the University of Melbourne and RMIT. Thermal imagery were provided by the City of Melbourne and the City of Port Phillip.**

PROJECT 10:
The impact of urban microclimate on human thermal comfort and health.

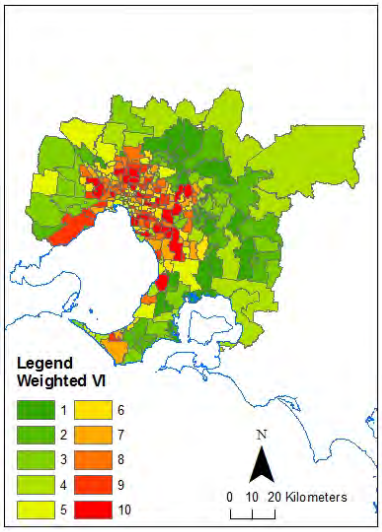
Increasing urbanisation and a changing climate has the potential to limit productivity and liveability within cities. In particular, predicted increases in hot days and heatwaves will enhance existing urban heat islands and increase discomfort and the risk of heat related illnesses. The greatest risk exists for the elderly, the very young, persons with chronic disease or disability, the urban poor, homeless people, persons working outdoors and people participating in recreational or sports activities.

Studies reporting heat-related health outcomes and human thermal comfort in urban areas have indicated that mean radiant temperature is the most important parameter for determining heat exposure; therefore providing shade is important in reducing exposure. Ventilation is also important, as is proximity to coastlines and water bodies. This project aims to understand human thermal comfort and heat-related illness within communities at three different levels.

1. Population vulnerability to extreme heat in cities.
2. Human thermal comfort and urban microclimates in public spaces.
3. Heatwave preparedness and household adaptation

Population vulnerability to extreme heat events in Australian capital cities

This project was supported by NCCARF and DCCEE and identified threshold temperatures at which mortality and morbidity increased in all Australian capital cities. Primarily the project developed a mapping tool to identify areas of high vulnerability during extreme heat events and predicted changes in the number of days exceeding threshold temperatures into the future for two time-slices (2020-2040 and 2060-2080). The key aim was to provide information to direct climate change adaptation with a specific focus on emergency management. The presence of UHI focused strongly in the research across all cities and was often associated with higher densities of vulnerable groups such as the elderly or culturally and linguistically diverse communities.



Mapped vulnerability index for Melbourne, the index was weighted using high-risk populations: the number of aged persons and ethnic communities. Decile 10 indicates areas of highest vulnerability.

See *https://sites.google.com/site/mappingvulnerabilityindex/home* and *http://www.nccarf.edu.au/sites/default/files/attached_files_publications/EM0901_Loughnan_2013_Extreme_heat_events.pdf*

Across the cities the highest vulnerability appears to be in areas with higher residential density and older established suburbs.

Heat extremes are projected to increase in all cities in the coming decades. Highlighting the areas most affected by extreme heat allows a targeted response and a focus for urban planning and policy.

Project 11: Human thermal comfort and urban microclimates in public spaces.

There is no global or absolute number that can reflect Human Thermal Comfort (HTC). Not surprising as humans occupy every climate zone, thermal comfort will be region specific. Human thermal comfort refers to 'that condition of mind which expresses satisfaction with the thermal environment' ASHRAE (ISO 7330) [1]. Perceptions of this environment are affected by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing. The current international ASHRAE standards are based on physiological measurements taken in climate chambers and refer to indoor environments. Adaptive models have been developed to assess outdoor HTC and suggest that humans are more tolerant of temperature changes than the laboratory studies indicated, and respond using physiological thermoregulation (unconscious response), behavioural adaptations (clothing, activity, location) and technological adaptations (windows, doors, blinds, fans, and air-conditioning, characteristics of a building such as materials, orientation, moveable shading, vegetation/green spaces) to maintain comfortable temperatures. In Australia adaptive models have been applied in Sydney but data for other capital cities are lacking.

This project undertook field surveys to apply adaptive models of HTC in both Adelaide and Melbourne. The field surveys involved 693 questionnaires and corresponding weather station data using static weather stations to collect and record ambient temperature, wind speed, humidity, solar radiation, and black globe temperature. Seventy-five percent of respondents were aged between 35-54 years.

Collecting surveys beside weather station and adjacent to a water body in Mawson Lakes 2011.

Overall the results indicated that persons walking or exercising in the thirty minutes before answering the survey were statistically more likely to report feeling very warm to hot. Consideration should be given to protecting exercise areas and public thoroughfares to limit exposures. People who were outdoors for the thirty minutes before answering the survey were hotter than those from indoor environments. The preference for more air movement (ventilation) increased as respondents recorded feeling hotter. Differences in thermal comfort between the two cities are highlighted, with thermally comfortable temperature ranges being higher in Mawson Lakes, Adelaide than Melbourne. Both cities show an approximately 3°C range in thermally comfortable temperature.

[1] ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers. Its purpose is 'to advance technology for the public's benefit, a mission it fulfils through research, standards writing, publishing and continuing education'. It has more than 50,000 members in more than 120 nations and sets the most widely-used international standards for buildings.

Thermal comfort reported as 4 (comfortable) median and interquartile points (ranges) for temperature.

Melbourne	
Percentile	Temperature (°C)
25th %	20.05
50th%	21.5
75th%	23.2
Mawsons Lakes	
Percentile	Temperature (°C)
25th %	25.3
50th%	25.7
75th%	27.9

The www.thermal comfort calculator indicated that at an ambient temperature of 28°C an average person in the sunshine for 30-minutes during the middle of the day would have an effective temperature of 33-36°C. Exercising outdoors in the sun changes their thermal comfort considerably. A person standing in the sun for 30 minutes at an ambient temperature of 31.5°C in summer will have a core body temperature of 37.06°C (within the normal range of 36.2-37.5°C), walking casually under the same conditions core body temperature rises to 37.8°C, walking briskly causes the core body temperature to rise to 38.98°C (this is an equivalent thermoregulatory response to a nasty viral infection). This increase in core body temperature can result in heat stress if exposure is prolonged. During hot/warm summer weather people need respite from the sun (solar radiation). The provision of shade and good ventilation is paramount in protecting humans from heat stress. HTC models indicated that persons in exposed environments either resting or physically active experience some level of heat stress. This can occur at lower ambient temperatures than expected. Public education is an important factor in heat stress mitigation as is modifying urban environments to reduce temperatures and minimise exposures. Differences in thermal comfort for two activities (sitting and casually walking in direct sunlight for 30 minute periods) are noted (see Table below). As activity increases thermal comfort decreases and core body temperature rises.

Developing liveable cities underpins urban development for the future. Greater insight into how humans interact within urban environments and what the limits are for human thermal comfort are needed to design thermally appropriate spaces. Reducing environmental heat exposure through water sensitive and climate sensitive urban design (CSUD) will provide a more liveable and healthier space for human activity. The results from this study provide information about thermally comfortable temperature ranges for two urban regions within Australia. Proponents of water and climate sensitive urban design can utilise this information to create urban spaces that are safe, productive, and socio-culturally acceptable spaces.

HTC for two activities levels for median and interquartile points of temperature in each city.

		Mawson Lakes			Melbourne	
Percentile (temperature)	Comfort model	Activity 1	Activity 2	**Percentile (temperature)**	Activity 1	Activity 2
25th% (25.3˚C)	SET	23.9	28.8	**25th% (20.5˚C)**	18.5	24.5
	TSENS	0.07(neutral)	0.73 (slightly warm)		0.28(neutral)	0.12(neutral)
	HIS	13.4	65.22		-1.56	44.9
	Core body temperature.	36.8	37.11		36.8	36.9
50th% (25.7˚C)	SET	31.04	33.8	**50th% (21.6˚C)**	21.8	25.9
	TSENS	1.60(warm)	1.65(warm)		0.14(neutral)	0.35(neutral)
	HIS	45.87	99.2		6.07	4.69
	Core body temperature.	36.92	37.3		36.82	37.02
75th% (27.9˚C)	SET	32.9	35.03	**75th% (23.2˚C)**	23.4	27.04
	TSENS	2.07(warm)	2.3 (very warm)		0.03(neutral)	.56 (slightly warm)
	HIS	54.69	107.92		11.8	52.04
	Core body temperature.	36.97	37.48		36.82	37.07

Notes

Activity 1 = sitting (60Wm^{-2})

Activity 2 = walking at average pace on level ground (150Wm^{-2})

All values for subject weight of 70kgs and clothing factor 0.6

Exposure time = 30minutes

SET = standard effective temperature

TSENS = thermal sensation

HIS = heat stress index

All calculations completed using WWW thermal comfort calculator (Richard DeDear)

Project 12:
Heatwave preparedness and household adaptation

The Intergovernmental Panel on Climate Change has reported that an increase in heat-related deaths is likely to be one of the most significant impacts of climate change for Australia in the future. Older people are particularly vulnerable to the impacts of climate change, particularly those with pre-existing illnesses, as well as people living in lower socioeconomic circumstances or within UHIs in larger cities. Alternatively, older people have much to offer the community in terms of what they have learned from a lifetime of responding to heat events, especially prior to the advent of air-conditioners. The aim of this study was to explore the behavioural and household adaptations used by a group of people in a northwest Victorian community regularly facing heat extremes. This area currently experiences summer temperatures comparable to the climate change scenarios predicted for Melbourne for 2050, the state capital. A mixed methods approach was employed, including a focus group session and household visits. Additionally participating households kept a daily diary noting their thermal comfort for the duration of the study period.

Results from the focus group interviews indicated that external drivers of heat-adaptive behaviours were primarily local weather patterns, and internal drivers were health risks and vulnerability to heat. However these drivers were moderated by (i) lack of recognition of heat-related risks, (ii) likelihood of increasing risk in a climate changed future, (iii) lack of access to heatwave plans and health information, and (iv) a sense of self-reliance; they felt confident they could cope with hotter weather. The household review data are summarised below. In general, the participants were healthy, independent, and socially and physically active. All had modified their homes and gardens to cope with heat. Forty-four per cent of the respondents did not consider themselves or others as vulnerable to heat. However 36% reported having specific health concerns that would increase their risk during heat events. Table 3 also shows that all respondents were involved in the local community activities, including social activities (sporting clubs and community groups), and in paid or unpaid employment, with many still working.

Household reviews also identified adaptive household characteristics including maintaining a garden (either independently or with support from family and friends). Fifty-six per cent of households had vegetative shading around the home and 72% had external pergolas or outdoor shade areas. Blinds and awnings to block out the heat were used in 48% of homes. All homes had at least one air-conditioning unit and fans were also frequently used. Ninety-eight per cent of homes were insulated. All of the participants maintained a garden around their homes, helping to moderate the household microclimate by providing shade and through being regularly watered. Outdoor living areas such as pergolas were used during the mornings and afternoons but not during extreme weather. These climate sensitive urban designs minimise the need to use air-conditioners with many participants restricting their use to cooling their bedrooms for 2-3 hours prior to going to bed, after which they opened windows to allow cross ventilation for a comfortable night's sleep.

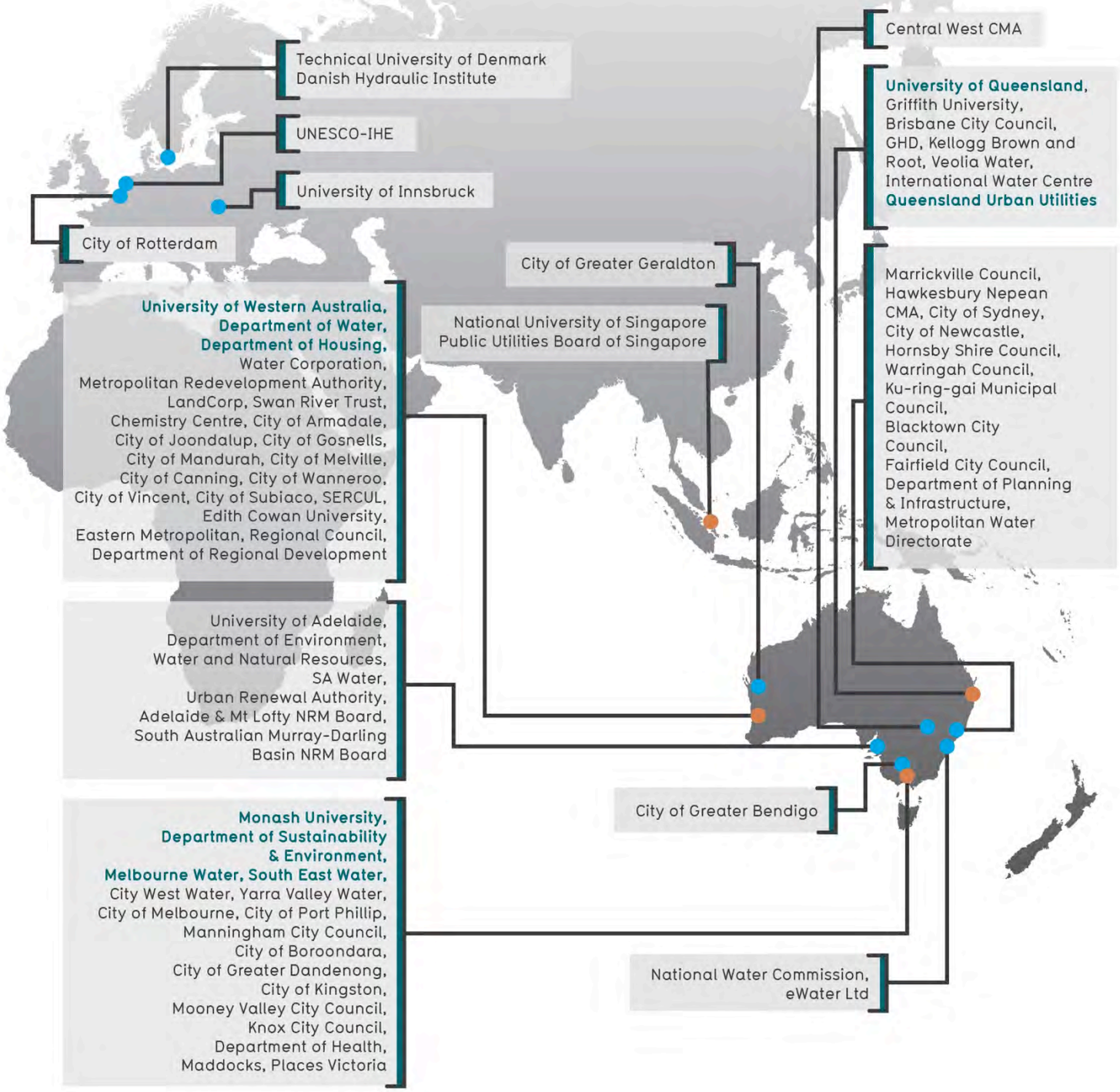
Household Interview Topic Areas and Results

Topic area			
Demographic characteristics	Age	Average 72.5 years	Average 72.5 years (Range 55-90 years)
	Gender	Male	15
		Female	11
	Household structure	Single person households	32%
		2 person households	68%
Health characteristics	Body Mass Index		Mean 28.7 KgM^2 (range 21 – 40)
	Heat-health concerns (e.g. CVD, diabetes, mobility issues)		36%
	Consider themselves as vulnerable to heat		56%
	Consider others as vulnerable to heat		56%
Activity & social connection	Sporting clubs/societies		100%
	Transport type:	Public transport	0% (limited options)
		Drive	95% (1 using a gopher)
		Walk	5%
Behavioural responses that moderate heat	Maintaining garden		100% (36% needing help)
	Watering garden:	Hand (watering can)	8%
		Hose	32%
		Irrigation system	40%
	Vegetation around house (grass, shrubs, trees, etc)		92%
Housing adaptations to moderate heat	Home modifications	Air-conditioning	100% (52% with 2+ units)
		Fans	72%
		Blinds and awnings	48%
		Verandas	24%
	Garden modifications	Pergolas/outdoor living areas	72%
		Insulation	98%
		Ceiling (only)	42%
		Walls & ceiling	56%
		Unsure	2%
		Shady plants	56%
		Pebble mulch in garden	8%
Housing stock	Age of home	Average 30 years	Range 4 – 96 years
	Duration of tenancy	Average 28.25year	Range 44 – 61 years
	Single/double storey	Double storey	12%
	Main building materials	Brick	44%
		Weatherboard	32%
		Cement sheeting	24%
	Roofing material	Tiles	56%
		Colorbond	44%
		Flat vs. pitched roof	24% flat roofs (1 both)
	Solar panels on roof		36%

The community connectivity, behavioural and environmental adaption described in this study supports the argument that individual and community resilience to heat is possible and already present in areas experiencing hot summers, and that these adaptations can reduce the growing dependence upon air-conditioning. There is a clear need for community-directed adaptation to best meet the needs of older people living in urban areas. This includes involving older people in community activities and integrating wisdom into generational change. Improving green infrastructure and passive cooling at a household level also helps to reduce heat exposure in and around the home.

CRC for Water Sensitive Cities: Partner Organisations

30 Local Governments
14 State Government Departments/Agencies **(3 Essential Participants)**
12 Research Organisations **(3 Essential Participants)**
8 Water Utilities **(3 Essential Participants)**
4 Land Development Organisations
4 Private Companies
1 Federal Government Agency
1 Community Group
1 Training/Capacity Building Organisations



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