PLANNING FOR A COOLER FUTURE: GREEN INFRASTRUCTURE TO REDUCE URBAN HEAT

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- Urban populations experience higher temperatures than people in un-developed rural areas due to increased heat production and retention by urban surfaces and structures
- With a changing climate, urban populations will experience more frequent extreme heat events, which can lead to increased rates of mortality and morbidity
- Green infrastructure (GI) can help mitigate high urban temperatures
- The key steps in mitigating urban surface temperatures to minimise high daytime urban temperatures are
    - Identify priority locations based on assessments of exposure and vulnerability
    - Maximise the effectiveness of existing GI by integrating water sensitive urban design
    - Identify priority streets for temperature reduction based on street orientation and height:width ratio, which determine the amount of sun exposure
    - Select appropriate GI for different environmental conditions
- A range of options are suggested for policies to leverage GI implementation at local, state and federal levels.

This guide synthesises research from the Victorian Centre for Climate Change Adaptation (VCCCAR)-funded project *Responding to the urban heat island: Optimising the implementation of green infrastructure*. Detailed literature reviews of the international scientific and technical literature as well as novel research undertaken during the project underpin this implementation guide. The relevant reports are listed below and are available at http://www.vcccar.org.au/responding-to-urban-heat-island-optimising-implementation-green-infrastructure.

Literature reviews

Harris & Coutts (2011) "Airborne thermal remote sensing for analysis of the urban heat island".

Hunter Block, Livesley & Williams (2012) "Responding to the urban heat island: A review of the potential of green infrastructure".

Research reports

Bosomworth, Trundle & McEvoy (2013) "Responding to the urban heat island: Optimising implementation of green infrastructure, A policy and institutional analysis".

Coutts & Harris (2012) "A multi-scale assessment of urban heating in Melbourne during an extreme heat event and policy approaches for adaptation".

Norton, Coutts, Livesley & Williams (2013) "Decision principles for the selection and placement of green infrastructure to mitigate urban hotspots and heat waves".

Policy brief

"Urban heat reduction through green infrastructure: Policy guidance for State Government"

What is the urban heat island?

The 'Urban Heat Island'(UHI) is a phenomenon where urban areas show higher temperatures than surrounding rural landscapes both during the day and in the evening. The UHI has been characterised in many cities around the world [3, 4] including Melbourne, which has a distinct UHI thermal profile on hot nights (Figure 1).

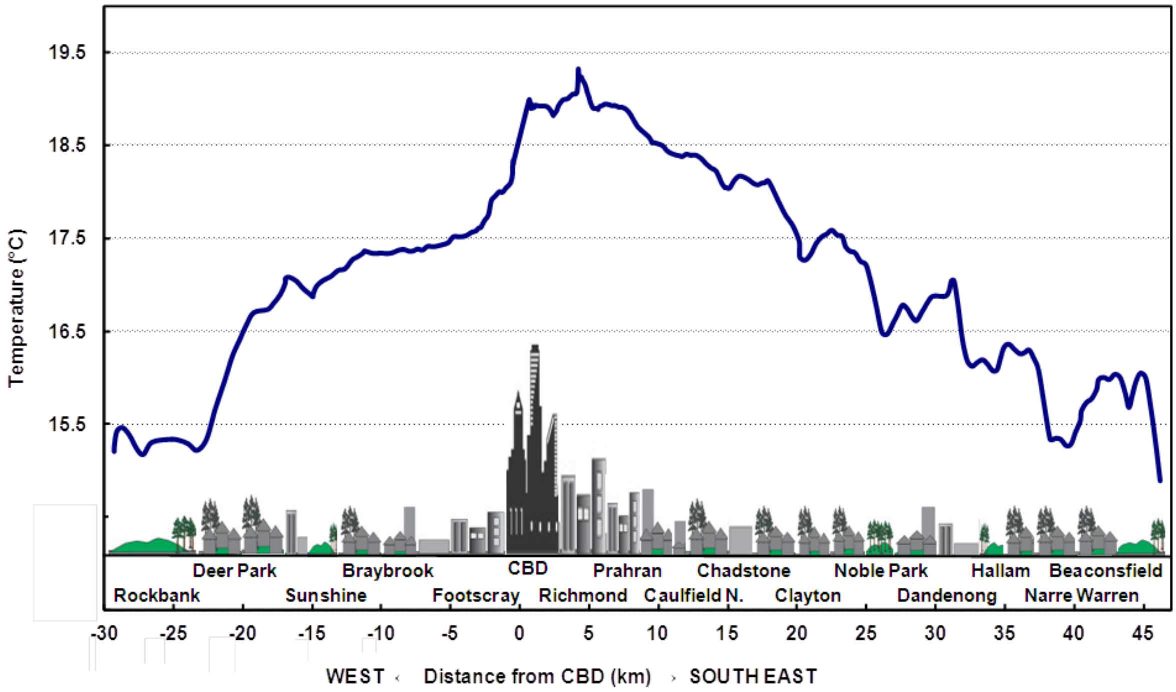


Figure 1: Spatial variability of the Melbourne urban heat island at 1 am, 23rd March 2006. [from 5].

Key drivers of UHI include [4, 6]:

- Vegetation removal - reduces shading and evapotranspiration;
- Increased impermeable surfaces e.g. asphalt and concrete - high stormwater runoff that reduces soil moisture available for plants, which in turn reduces evaporative cooling;
- Construction materials with high heat capacity and low reflectance, e.g. terracotta tiles, bricks, bitumen and concrete - these materials absorb, trap and re-radiate heat;
- Dense urban arrangements - absorbs and traps heat;
- Heat production from machinery (cars, air conditioners etc);
- Air pollution that creates a local 'greenhouse' effect.

Why are high urban temperatures a concern?

People living in urban areas are particularly at risk of heat-related disease and death because they are already exposed to high temperatures. International research indicates that localised temperature increases in urban areas due to urban development already exceed temperature increases projected by climate change models [7, 8].

Heatwaves have been projected to become more frequent under global climate change [9], placing more people at greater risk of heat-related disease and death. Heatwaves are a major threat to human life globally. For example, between 35,000 and 50,000 people died due to heat related illnesses in Europe during the heat wave of summer 2003 [10, 11]. Over the last two centuries **, heatwaves have claim more Australian lives than any other natural hazard** [12]. In Victoria, a heatwave in January 2009 was linked to 374 excess deaths [13]. Urban residents must adapt to the compounding effects of elevated temperatures from both high urban temperatures and climate change.

The issue of urban heat is important in Australia because this country has already hot summers, and is one of the most highly urbanised nations in the world, with 80% of the population living in major cities [14]. **Victoria's urban populations continue to grow. For example, Melbourne is projected to grow to 6 to 8 million people by 2056** [15]. The increasing frequency of heat waves and the increase in urban development are therefore urgent issues in Victoria [13, 16].

Areas that become particularly hot in Melbourne and other cities around the world are not evenly distributed, and socially disadvantaged groups often experience greater urban heat exposure. Certain sections of the community are also more vulnerable to heat exposure, particularly the very young, the frail elderly and those with a pre-existing physical or mental illness [17-19]. Appropriately targeting neighbourhoods for temperature amelioration is therefore an important issue of social justice, as well as serving as an important mental and physical preventative health measure [20].

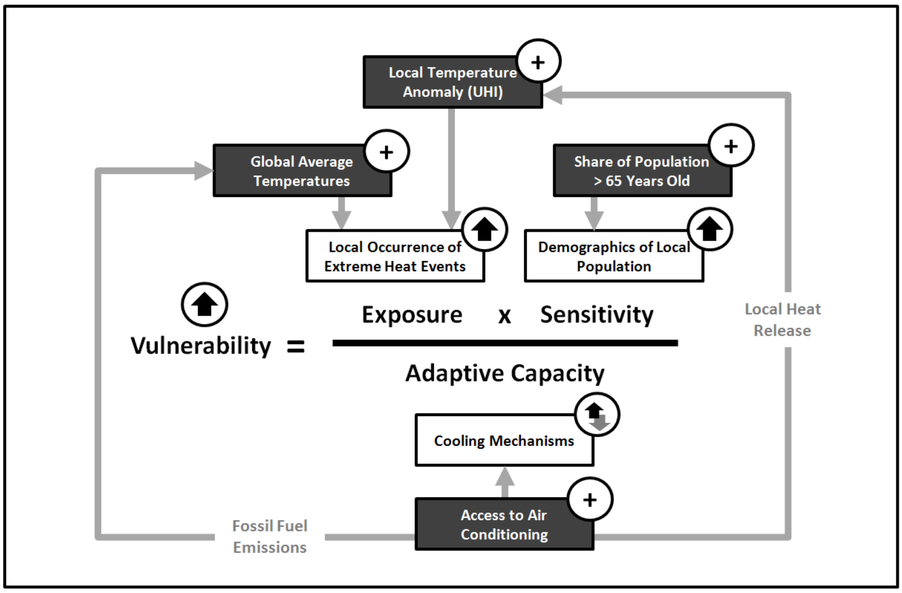


Figure 2.Representation of current and projected extreme heat vulnerability in Melbourne. Green Infrastructure is a cooling mechanism that does not create fossil fuel emissions.

Urban heat at different scales

The scale of heat production and retention in urban areas is important in understanding the development of the UHI and strategies for UHI adaptation. The UHI is a city-wide phenomenon and is most often described by comparing temperatures in the CBD to the city's rural surrounds, giving a maximum UHI intensity. Yet across an urban area temperatures will vary with changing land use and land cover, creating street- and neighbourhood-scale areas of excess heat, or 'hot-spots'.

People's experiences of the climate and high temperatures occur mostly at the micro-scale, in the layer of air between the ground and the top of roofs or trees, which is known as the 'urban canopy layer' (UCL). The climate experienced at the micro-scale is influenced by the immediate surrounding environment (e.g. street environment), the local-scale climate (e.g. neighbourhood environment) and the city-wide (meso-scale) climate (e.g. synoptic influences and the UHI) (Figure 2).

The city-wide UHI is the combined result of heat production and/or retention at the micro- and local scale. **The focus of this document is on mitigating excess urban heat at the micro-scale and local-scale through the use of vegetation**. Modifications of the environment at these scales will influence people's experience of the climate within the UCL and can have flow-on effects to larger-scale climatic processes including the reduction of the UHI if implemented over large areas.

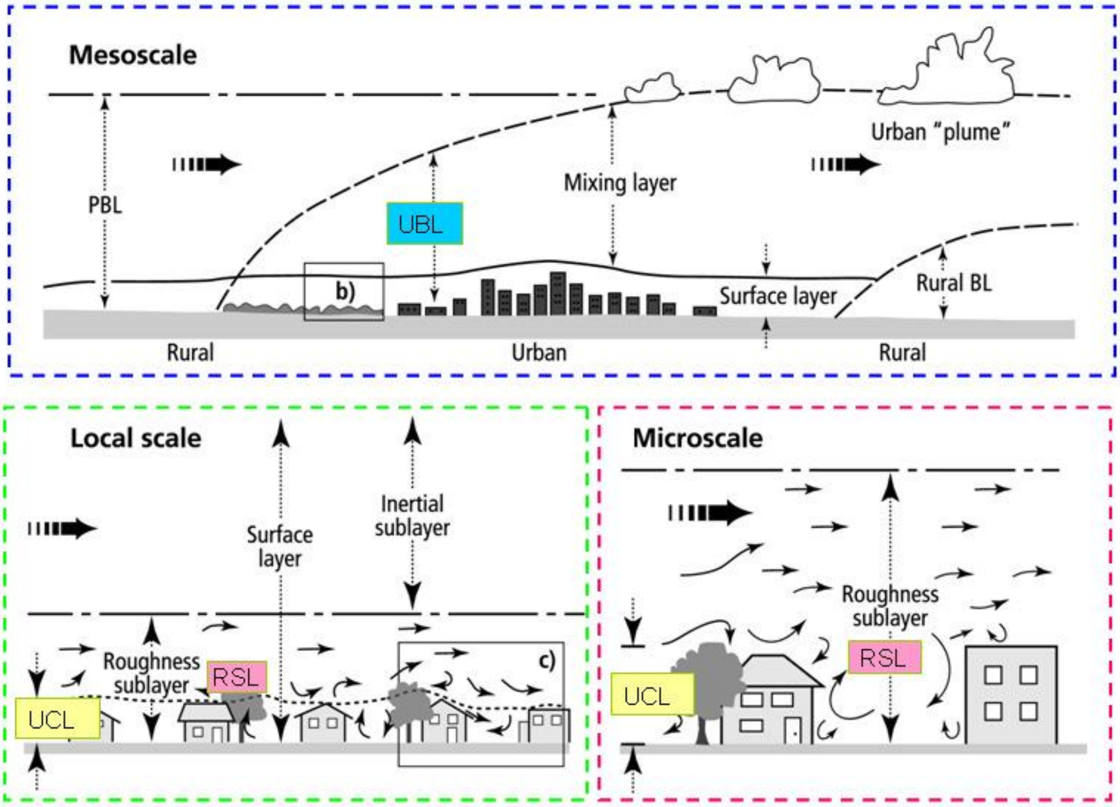


Figure 3: The different scales of urban heat retention and the urban heat island effects. RSL refers to the Roughness Sub Layer, UCL is the Urban Canopy Layer, and UBL is the Urban Boundary Layer [21].

The UHI is not a single phenomenon. There are actually several types of UHI, which describe different components of urban heat. The 'classic' UHI effect refers to changed air temperatures within the UCL (Figure 2). This UHI is most pronounced on warm, still, summer nights, when inner urban air temperatures can be 3.5 – 4.5 °C warmer than surrounding rural areas [22]. It is particularly strong in areas of high building density, for example the CBD (Figure 1).

A second UHI is the **surface UHI**. The surface UHI refers to the temperatures over the full three-dimensional surface of a city, e.g. roofs, walls and street surfaces. The surface UHI is affected by solar radiation and so the largest temperature differences are most pronounced during the day [23], particularly in open areas exposed to direct sunlight. Solar radiation has also been shown to be one of the key factors in determining human thermal comfort under hot conditions.

This document focuses on reduction of high urban *surface* temperatures. Surface temperatures generally change in the same direction as air temperatures but, during the day, surface temperatures are much higher. They are a useful target for mitigation because they are not influenced by wind as much as air temperature and so are easier to compare accurately between areas. Surface temperatures can readily be measured at multiple scales within the city (Figure 3). They also contribute to air temperatures and to high urban temperatures overall. Consequently, **reduction of surface temperatures will contribute to reduced air temperatures during both day and night**.

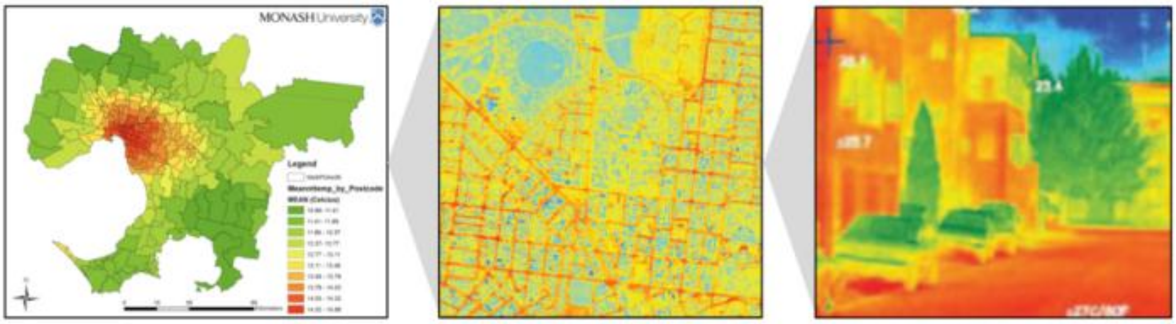


Figure 4: Urban surface temperatures measured at different scales (from left to right): Greater Melbourne using satellite data [1]; at the neighbourhood scale using airborne thermal imagery; and at the street-scale using a thermal camera [2]. Red indicates high temperatures, green and blue are lower temperatures.[3]. Street scale (image from urban-climate-energy.com) Note temperature colouration scale varies between images)

What is green infrastructure?

Green Infrastructure (GI) is the network of designed and natural vegetation found in our cities and towns, including public parks, recreation areas, remnant vegetation, residential gardens, street trees, community gardens, as well as innovative and emerging new urban greening technologies such as rain gardens, green roofs and green walls.

The role of GI in mitigating high urban temperatures

Without concerted actions and planning, our changing climate will further amplify the serious impacts of high urban temperatures. Many cities are starting to address the challenge of increased urban temperatures through a variety of approaches including water sensitive urban design (WSUD), painting surfaces white or pale colours, strategic urban design, and green infrastructure implementation. For optimal climate regulation in urban areas a range of strategies will be necessary.

This guide focuses on the use of green infrastructure (GI) to mitigate urban heat. GI is an effective means to minimise heat accumulation in the urban environment as it shades hot surfaces, increases evapotranspirative cooling and modifies wind patterns The guide provides advice on spatially strategic ways to reduce urban surface temperatures across Greater Melbourne using increased cover of GI. Surface temperatures are an excellent target for mitigation by GI because sun exposure is a key driver of increased urban surface temperatures, and GI reduces this exposure through shading (e.g. trees) or covering these urban surfaces (e.g. green walls).

Green infrastructure is an effective and socially appealing means to minimise heat accumulation in the urban environment. It maximises cooling by vegetation and delivers numerous other environmental and social benefits, with significantly less energy use and greenhouse gas emissions than alternatives such as air conditioning.

While the cooling effects of GI are the focus of this guide, **GI has a multitude of additional environmental and societal benefits.** These benefits include: reduced energy use, the provision of accessible green spaces for urban dwellers; improved human health; storm water capture and retention; increased urban amenity and house prices; the creation of biodiversity habitat; noise attenuation; and pollution reduction [24-27]. While not explicitly addressed within this guide, these additional benefits can contribute to the liveability of our urban areas and can help build a business case for GI investment.

Purpose of this guide

This guide is for local governments and planning consultants who make decisions about how to address the risk of high urban temperatures during summer months and are considering the use of GI. **It focuses on established urban areas**. The principles presented here could also be used to inform planning and design of greenfield sites. There is also a greater potential in new urban developments to use a range of additional approaches to reduce urban heat including using urban design such as street orientation and width to moderate climatic conditions [28-30].

This document focuses on temperature reduction of public open space, as the authors recognise that councils have greatest control over public rather than private domains. There is likely to be flow-on temperature reductions to private spaces and the insides of buildings from following this guidance.

The information provided here should provide an **addition to the suite of tools used by landscape management professionals** (e.g. landscape architects, urban planners, engineers) but it is not a comprehensive information pack. Further information can be found in the research that informed this guide and the scientific literature listed in the Reference and Further reading sections.

KEY STEPS FOR GI IMPLEMENTATION

This guide presents a series of steps for informing a strategic plan to address urban heat through the use of GI. More information about each of these steps can be found in Norton *et al.* (2013, VCCCAR). While a strategic plan would address a whole Local Government Area (LGA), the scale of implementation at which this guide is targeted is the local and 'micro' scales (Figure 4).

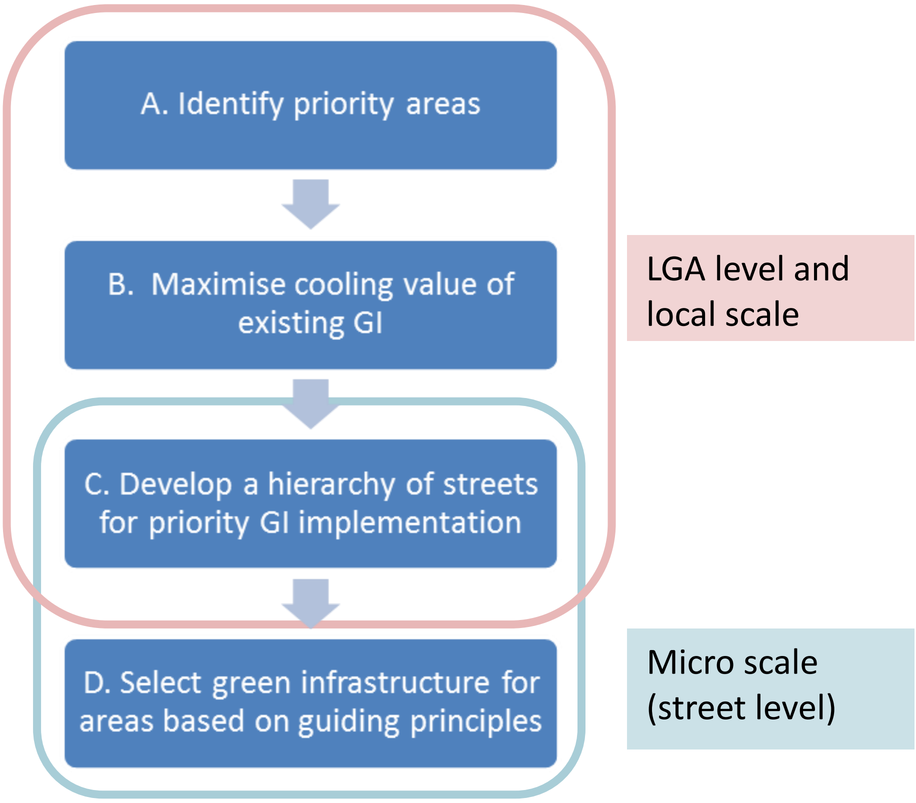


Figure 5: Steps for the selection and location of green infrastructure for cooling surface temperatures contributing to high daytime urban surface temperatures.

IDENTIFY PRIORITY 'NEIGHBOURHOODS'

It is important to prioritise GI that reduces exposure of vulnerable sections of communities to excess urban heat. Whether a heat-health outcome (e.g. morbidity or mortality) occurs is dependent on a person's 'exposure' to excess heat, and their underlying 'vulnerability' to that heat [31]. Areas where both exposure and vulnerability are high should be prioritised for GI implementation. To assess exposure, information about temperature patterns during extreme heat events and locations of important community infrastructure, is required (Figure 5). Councils and planners are advised to work with their community development experts to identify groups or locales that may be particularly vulnerable to urban heat.

Assess exposure

At the scale of the greater metropolitan area, **there is significant temperature variation across Melbourne's urban areas**; western and southeastern regions tend to experience higher day time temperatures and lower night time temperatures in contrast with the inner city and some suburbs in the east where the opposite pattern occurs [1, 20]. There is also significant temperature variation within each of these regions.

Assessing heat exposure requires the documentation of areas of excess heat or 'hotspots'. It is difficult to collect detailed air temperature data across a large spatial area as it requires expensive and laborious data collection. An alternative approach is the use of remote sensing, which provides a snapshot in time of land surface temperature across a large spatial area.

Determining particularly hot areas can be achieved quite cost-effectively using **satellite thermal remote sensing**. Various products are available for free from the NASA website including Landsat ETM+ (Enhanced Thematic Mapper) and ASTER at resolutions of 60 m (re-sampled to 30 m) and 90 m respectively. These resolutions are suitable for identifying hot-spots across a local council area which can then be targeted for GI intervention.

Higher resolution (1-5m) thermal remote sensing data can be obtained via **aircraft mapping**. However, the expense of these measurements and the long data processing times required to obtain quality data make satellite remote sensing a more cost-effective option. A detailed discussion of these issues can be found in Coutts and Harris (2012, VCCCAR).

At local and neighbourhood scales (within an LGA) not only is it important to identify areas of high temperature, but to identify areas within these neighbourhoods where pedestrians will be active and exposed to direct sun during the day. **Areas with high pedestrian activity** should be identified and prioritised. These areas include known activity centres such as the CBD, central Dandenong or Footscray, shopping strips, public transport interchanges, the location of aged care facilities, pedestrian thoroughfares, schools and the streets around them and areas close to kindergartens.

Assess population vulnerability to heat

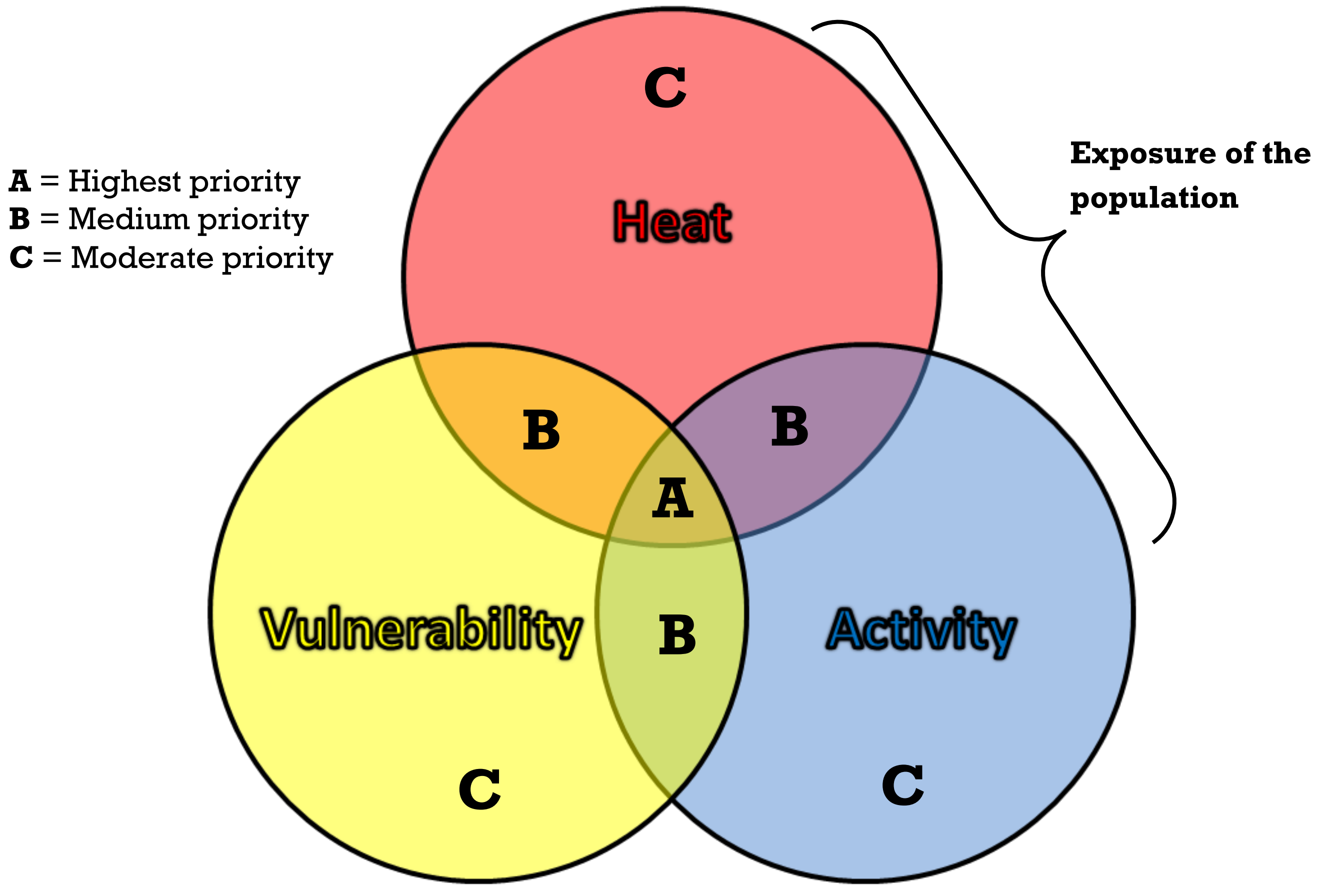
Some groups of people are particularly vulnerable to heat stress during extreme heat events. Ascertaining where these groups might be, who they are, and what temperature is considered a risk has become a major research area [e.g. 32, 33-36]. In Melbourne, Loughnan *et al.* [1] identified **five key indicators of vulnerability to urban heat**. These were areas with:

- a high proportion of elderly and very young citizens,
- large numbers of aged care facilities,
- families speaking a language other than English at home,
- where elderly people live alone,
- suburban areas (in contrast to high-density inner suburbs).

Areas with high representation of these populations could be identified when selecting priority neighbourhoods for GI implementation. Loughnan *et al* [20] have developed a map of a Vulnerability Index for Melbourne at the scale of the census district based on key factors that influence vulnerability. Maps of ambulance call-outs on hot days were also developed [20]. Such maps can be used to identify priority areas for greening based on population vulnerability. The maps are available online at http://www.mappingvulnerabilityindex.com/. A similar approach to that used by Loughnan *et al.* [20] could be followed at smaller scales to help identify vulnerable locales using accessible data from the Australian Bureau of Statistics such as age and Index of Relative Socio-Economic Disadvantage.

Finally, when planning urban greening to reduce risks associated with extreme heat events, it is important to consider **population projections** and demographic changes as well as the current population structure. Information about expected population growth and demographic patterns to 2026 is available from the Department of Planning and Community Development website [37]. Projections of future land use change of areas should also be considered.

Figure 6: Venn diagram representing factors required to identify areas of high (A), medium (B) and moderate (C) priority for GI implementation for surface temperature reduction. The key factors are daytime surface temperatures (Heat) and areas of high activity (Activity), which combined indicate areas of high exposure. In addition, areas with high concentrations of vulnerable population groups (Vulnerability) should be identified.



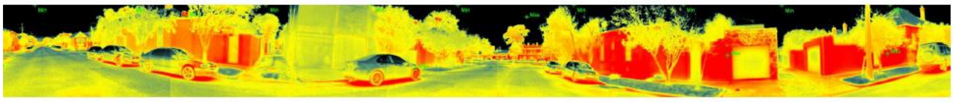
Maximise the cooling value of existing GI

An important first step in mitigating high urban temperatures is to **maintain healthy GI to provide the maximum possible temperature reduction.** All GI reduces micro-scale daytime temperatures most effectively when irrigated and indeed some forms, particularly grass and green roof vegetation, are unlikely to survive or may go dormant during hot, dry summers without additional water. For example, a study in Melbourne found that non-irrigated grass was on average between 3.6°C and 5.2°C hotter than watered grass (Coutts and Harris, 2012, VCCCAR). Sufficient irrigation contributes to plants reaching their growth potential and, given other prevailing conditions, providing the maximum amount of shade possible.

Urban vegetation can often be under water stress because large areas of impermeable surfaces prevent rainfall infiltration. To ensure the cooling services of GI are maximised at the time of year when they are most required, adequate water supply is critical. This can be achieved through the use of alternative water supplies such as sewage recycled water systems and grey water or storm water capture, storage and redistribution. Increasing the cover of permeable surfaces, for example by using water sensitive urban design, would also increase water availability to plant roots. Exemptions from water restrictions could also be sought.

GI should be assessed for its water requirements particularly for extended periods of high temperatures and low rainfall. Plants considered to have insufficient available water should be irrigated. Implementation of **any new GI should incorporate adequate water access.** Despite its importance, the water requirements of urban vegetation to maximise cooling remains a knowledge gap and priority research issue. A mix of native and deciduous vegetation types should be promoted, as this diversity can increase resilience across a range of climatic futures. Creating xeric (desert) like landscapes with un-irrigated, drought tolerant vegetation will not be as beneficial for heat mitigation.

PRIORITISING STREETS



Once priority neighbourhoods have been determined, priority streets within those areas need to be identified based on properties of the '**street canyon'**. This is a standard measure of the urban environment, encompassing the width of the street (plus footpath, front gardens etc) that is bounded by two buildings usually along the length of a block. It is often conceived in cross-section. Street canyons are a useful unit for planning because their geometry and orientation are very important determinants of surface temperatures in urban areas [38, 39]. Key properties of urban canyons are:

- Building height (H): This is the height of the buildings on one side of the street. In the simplified canyon scenario buildings are the same height on both sides of the street
- Canyon width (W): The distance between the front of the buildings on either side of the street
- Height to width ratio (H:W). Canyons with high H:W are tall and narrow, and those with low H:W are short and wide. Consistent relationships can be developed based on H:W that are not possible using the H and W measures separately
- Sky view factor (svf): the amount of sky visible from the ground. This will be reduced if H:W is high (tall, narrow canyon) or if there is a lot of vegetation in the canyon. Svf affects how much heat can be released into the atmosphere, particularly overnight.
- Orientation: direction of the street, e.g. north-south, east-west, diagonal
- Length of the canyon: the length of the street along one block

Selection of green infrastructure should be based on two key features of street canyons:

1. Height and width
2. Orientation

Canyon height and width

Wide canyons receive more sunlight because they are less shaded by buildings and therefore can have very high surface temperatures. Similarly because their surfaces are more open to the sky, they cool relatively quickly at night. **Wide canyons are therefore targets for GI** to increase shade and reduce their heat accumulation during the day (Figure 6).

Narrow canyons with tall buildings are generally well-shaded because the sun can't reach the ground. At night, the tall buildings and narrow streets trap heat and don't allow the surface to cool down as quickly. This type of canyon structure is where the classic urban heat island is most evident. Considering the aim of reducing high surface temperatures, deep, narrow canyons are lower priorities for GI implementation for cooling during the day because of the greater amount of self-shading (Figure 6). Deep, narrow streets will still benefit from GI installation on the canyon floor and lower walls in particular, especially if there is high pedestrian activity. **Narrow canyons with low buildings are also a priority for mitigation** (Figure 6) because they are less shaded than canyons with tall buildings and they can heat up depending on their orientation. However, space restrictions in narrow canyons may mean green facades or hedges might be selected over trees.

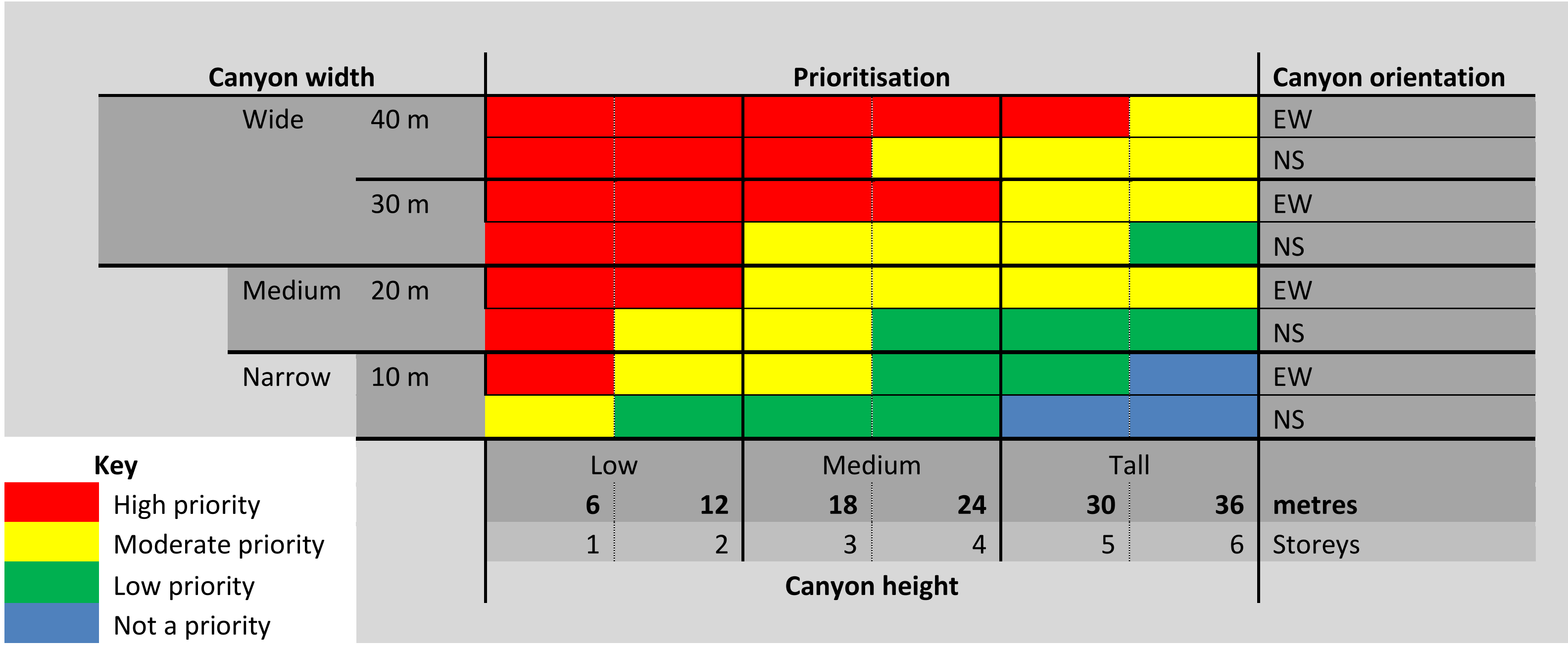
Street orientation

Streets orientated north-south (or close to) will experience the majority of their sun exposure in the middle of the day. The west-facing (east) side of the street is likely to get the hottest because it receives the afternoon sun. **North-south orientated canyons are lower priority targets than east-west canyons, unless they are very wide** (Figure 6).

Streets orientated east-west (or close to) will experience direct sun throughout the majority of the day. **East-west oriented streets are therefore high priorities** for GI to mitigate high urban temperatures (Figure 6).The north-facing (south) side of the street is likely to get the hottest because it receives direct sunshine throughout the day during southern hemisphere summers.

Surface temperature is highly dependent on the time of day and length of time a street is warmed by the sun. As a result, for streets on a diagonal, the further the street orientation deviates from north-south, the less self-shading there will be from buildings. Even relatively small changes from north-south can result in higher temperatures, but **priority diagonal streets should be those closest to an East-West orientation**.

Figure 7: Classification of streets in priority areas for GI-based reduction of daytime surface temperatures at the summer equinox. Priority is based on the extent of self-shading by buildings.



ANALYSE AND SELECT GI OPTIONS




Once priority locations have been identified, specific GI options need to be determined for each of those locations. The overall goal for urban temperature reduction using GI is to **maximise green cover**. To meet this goal at a city-wide or local government level, green open spaces will be critical because of the significant contribution they make to UGI cover. Within street canyons, the goal is to **maximise green cover particularly in highly solar exposed street**. So the primary goal is to **maximise 'overhead' vegetation canopy cover**. Overhead vegetation cover reduces canyon surface temperatures as well as providing shading and cooling. In most cases, tree canopies are the optimal solution for providing overhead vegetation canopy cover because they shade large areas if appropriate canopy structures are selected and well maintained. In addition, they provide many other co-benefits such as aesthetic and cultural value or the trapping of particulate pollutants [25, 40] (Table 1). Alternative overhead vegetation options include vine-covered archways.

A secondary goal is to **increase surface vegetation cover**, which is vegetation that covers either ground or wall surfaces. This reduces surface temperatures and increases transpiration, but does not provide shading. GI options for surface vegetation cover include vertical greening systems, green roofs and grassed surfaces (Table 1). These options are desirable in areas where tree installation is not possible. Surface vegetation cover provides additional benefits such as structural diversity, recreational space and increased permeability of urban surfaces. When applied directly to building surfaces, they can also provide significant benefits for building occupants and owners.

We focus here on five types of GI: green open spaces; street trees; green walls and green facades, in line with available evidence. If there are opportunities for other GI options, such as streetside plantings shrubs, these should also be considered to meet the overall goal of increased vegetation cover.

Urban green open spaces

Urban green open spaces (GOS) are primarily grassed areas with a relatively sparse (or absent) tree canopy, such as ornamental parks, sporting fields and golf courses, but also include remnant vegetation and urban agriculture. These areas can provide 'islands' of cool in hot urban areas. Depending on their size and the wind direction, they can also cool the surrounding landscape. Increasing the total area of green open spaces across an LGA or city leads to significant reductions in temperature at the meso-scale. As the largest form of GI, green open spaces are therefore critical in maximising the extent of green infrastructure at the city scale and innovative opportunities to create new GOS should be pursed. For example the City of Melbourne has recently created a new park in North Melbourne by removing and reducing the width of roads.

GOS are most effective for cooling at the local scale if they contain scattered trees and are irrigated. They also have lower interior temperatures if they are larger in size, but a strategy of many, smaller GOS would provide benefits to a larger number of people by providing accessible cooler spaces close to home. Larger GOS can provide cooling to areas downwind, and should therefore be **located upwind of priority areas** (Table 1). In Melbourne, extreme heat events are usually associated with high pressure systems East of Victoria, which bring warm continental air from the North. Locating GOS to the north of priority areas should increase their benefit e.g Royal Park for Melbourne's CBD.

Trees

Trees reduce surface temperatures by reflecting and absorbing solar radiation, thereby providing shade. Trees also cool the surrounding air at the micro scale through canopy transpiration (Table 1). **Increasing tree canopy coverage is one of the most cost-effective strategies for cooling buildings and local neighbourhoods**. However, urban environments are often hostile environments for tree growth, with high levels of impervious surface cover, low soil moisture, changed soil properties and high pollution loads. As a result, the magnitude of cooling may not be as great for street trees as trees in urban parklands or rural areas. Shade provision by trees depends on both their trunk and branches, as well as the leafy canopy. Broad, wide and short trees are particularly effective at shading pedestrians. Trees that retain a thick canopy with high leaf area density provide particularly good shade, meaning that broadleaf trees are generally more effective than needle-leaf trees. Deciduous trees should be considered where heat gain in winter is also desired.

Not all tree species possess the same capacities for heat and drought tolerance. The City of Melbourne's *Urban Forest Strategy 2012-2032* (City of Melbourne 2011) provides a useful set of guidelines for tree species selection in different urban contexts, highlighting the tradeoffs in service provision and survivorship of trees. Information relevant to the drier, western suburbs can be found in the Hume City Council *Street and Reserve Tree Policy 2004* (Hume City Council 2004).

The arrangement of trees within the street canyon will influence how effectively they reduce temperatures. Table 1 provides guidance on designing the most effective arrangement. In some cases there is likely to be competing demands for trees with other infrastructure such as overhead powerlines. Where existing infrastructure cannot be changed, climbing plants can be trained on supporting structures to avoid other infrastructure while still providing overhead shading.

A diversity of tree species can be important in moderating temperatures throughout both the day and night. Trees that provide the greatest shade during hot summer days can also trap heat under their canopy at night. To minimise the amount of heat trapped, street trees should not form a continuous canopy, thereby allowing hot air to escape in the spaces between trees. A mix of tree species with different canopy architectures could be considered for the same reason. Aiming to create and sustain an urban forest with species diversity can also increase climate change resilience and provide a diversity of ecosystem services.

Green roofs

A green roof is a roof that uses vegetation to improve its appearance, environmental performance or both. During the day, **roofs are some of the hottest surfaces in urban areas** and green roofs can potentially play an important role in mitigating urban temperatures at a meso-scale, as well as reducing temperatures inside buildings through insulation.

There are two commonly used classifications of green roofs. Extensive green roofs have thin growing media (2-20 cm) that can support a limited range of small plants, while intensive roofs have a thicker layer of growth media that can support a wider range of plants including large trees and shrubs, and can be considered as rooftop parks. Most green roofs are 'extensive', because they are lighter and cheaper to install and can be retrofitted to a wider range of buildings. They have been successfully used in northern hemisphere cities for cooling roofs, but in the hot, dry summers in Australia, keeping plants alive has been a greater challenge.

Green roofs have been found to **provide the best reduction in surface temperatures when they have high vegetation cover**, with dense, green leaf cover, preferably with large leaves and with a variety of different vegetation heights, and are irrigated. Unfortunately, the more common extensive green roofs are generally only capable of supporting small plants and groundcovers, with *Sedums* being the most popular choice in the northern hemisphere. Achieving a balance between maximising the performance of green roof vegetation for cooling during Australia's hot summer conditions, while keeping plants alive in shallow soils with minimal irrigation is an ongoing area of research. Further information is being prepared on the requirements for green roofs in southeastern Australia as part of the Growing Green Guide Melbourne (see http://growinggreenguide.org/).

The extent of the cooling benefit of green roofs is not yet clear. Modelling studies suggest that green roofs can play a role in UHI mitigation. This positive effect may only come from extensive installation of irrigated green roofs – over many buildings and particularly on large roofs. Their influence on cooling at street level will be low unless the roof level is close to ground level. For urban cooling, we recommended them primarily for **large, low buildings, or for implementation in areas with little space for ground level urban greening** (Table 1).

Vertical greening systems

The term 'vertical greening system' (VGS) refers to vegetation that is growing on, or very near, a wall. There are two main categories of vertical greening: **green facades and green (or living) walls**. Green facades are climbing plants growing up a wall, either directly onto the wall surface (direct green facades) or up a trellis or similar structure set slightly away from the wall (double-skin green facades or green curtains). Green facades can be planted in the ground or in planter boxes at any height up the sides of a building. As well as preventing heat gain to buildings, green facades can beautify urban areas and provide cooling through transpiration. Green or living walls are comprised of plants grown in modular panels or hydroponic felt curtains attached to the wall. However, these tend not to be a realistic option for wide spread implementation because of their high installation, life-cycle and ongoing maintenance costs.

VGS cool through shade and transpiration, they cover surfaces that would otherwise trap and store heat, and, when grown on building walls, provide insulation (Table 1). VGS are **beneficial on any wall with direct solar exposure where street trees cannot be grown.** Walls that are already light coloured should not be the first target of adaptation as they do not become as hot as dark coloured walls. VGS are **beneficial in narrow canyons** where space at ground-level is at a premium, but **also wide streets with barriers for tree growth** such as electricity wires and trams (Table 1). In these situations a hedge or a trained climbing plant may also be an option. To benefit pedestrians, VGS must be installed adjacent to walkways, for example on walls that abut the footpath (Figure 7) or on fences.

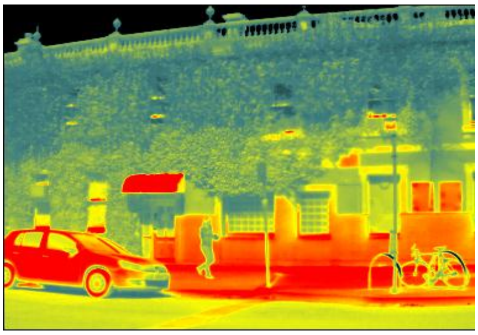


Figure 7: Green facade in inner-Melbourne during the day. Blue indicates lower temperatures and red, higher temperatures (image taken with a thermal camera. Photo: R. Harris)

As for green roofs, the knowledge base in Australia for the installation and management of VGS's is, as yet, scant. This is compared to the extensive European literature, especially from Germany. Research is ongoing, and guidelines for the installation and management of vertical greening systems are being developed (See Growing Green Guide Melbourne. http://growinggreenguide.org/)

Table 1: Cooling properties of green infrastructure options during summer

UGI	Shades canyon surfaces?	Shades people?	Provides building insulation?	Increases solar reflectivity?	Evapo-transpirative cooling?	Priority locations
Green open spaces	Yes, if grass rather than concrete used	Yes, if treed	No	Yes, when grassed	When water is available to plants during hot, dry periods - Yes No – if no water available	•High-density housing. •Upwind of vulnerable communities •Retrofit to dead-end streets
Trees	Yes	Yes	No, unless well-positioned	Yes	Yes	• *Wide streets with low buildings* – both sides of the street • *Wide streets with taller buildings* – sunny side of the street (south side of east-west streets, west side of north-south streets) • In GOS
Green roofs	Shades roof, not internal canyon surfaces. Depends on plant selection	No Only on certain intensive roofs	Yes Plant and substrate selection are important	Yes, if plants are healthy	When water is available to plants during hot, dry periods - Yes No – if no water available	•Sun-exposed roofs •Poorly insulated buildings •For street-level benefits: low, large building •Dense areas with little room for ground-level greening
Vertical greening systems	Yes	No	Yes	On walls adjacent to pedestrian footpaths - Yes On walls away from pedestrians, e.g. behind a fence - No	When water is available to plants during hot, dry periods - Yes No – if no water available	•Any canyon wall that receives direct sunlight •Narrow or wide canyons - in areas with pedestrians and where trees aren't possible

A sound policy framework is key to enabling strategic implementation of GI in urban areas. New, or changes to existing policies, regulations, standards and guidelines should be considered to encourage or mandate GI during land use planning, land acquisition and development and urban design. It is also important to ensure that existing policies and standards do not pose an unreasonable barrier to GI. Bosomworth *et al.* (2012, VCCCAR) lists a range of example policies that could support council efforts to implement a strategic GI plan.

Public Realm

Policies governing the management and sale of urban public land were reviewed as part of the Victorian Environment Assessment Council's Metropolitan Melbourne Investigation [41] which explicitly recognised the value of public land for mitigating excess urban heat and the community's concerns regarding its loss and the impact of Melbourne's rapidly growing population. Implementation of many of the report's recommendations would positively influence the provision of GI in Melbourne and should be pursued. These include a no-net-loss policy for public open space and changes to the subdivision act to ensure developer open space contributions for inner and middle ring local councils not just those on the urban fringe. One example, the City of Melbourne have proposed a planning scheme amendment (C209) that would require developer cash contributions of 5%, and 8% of the value of a site, land contributions in areas with an identified open space shortage or both.

Government should also consider requirements for green infrastructure contributions from developers where zoning changes allow multi-unit residential development without subdivision. For example, planned development overlays along transport routes will significantly increase building density and therefore heat retention. Green infrastructure contributions could potentially be used to finance increased street tree plantings or water sensitive urban design initiatives that increase the effectiveness of existing GI.

Other potential public realm policy changes supporting GI include:

- Protection of existing GI through greater penalties for illegal destruction of trees;
- Pursuing opportunities to create additional GI through the closure of streets to create new or expanded local parks. Successful examples include Barkly Gardens in Richmond and Errol Street in North Melbourne http://www.victoriawalks.org.au/pocket_parks/ ;
- Coordinate investment of limited resources by working with agencies such as VicRoads, Public Transport Victoria and gas and water retailers to implement UGI when they are doing works for other purposes. Having a dedicated budget for opportunistic works could facilitate this as could utilising programs such as City West Water's co-funding model.

Encouraging public understanding of the value of GI for urban cooling should also be explored as a means of developing community advocacy for increased GI. Providing resources, such as open space and corresponding heat maps on council or state government websites or in local newspapers, will enable people to determine the amount of GI in their neighbourhood, and the environmental and economic benefits this may bring relative to other areas. Residents who perceive their neighbourhoods to be lacking GI may lobby for increased planting of local GI.

Private Realm

A supportive policy framework to provide commercial and residential GI could use combinations of regulations and incentives, supported by provision of information and advice. Regulations could include provisions to keep a percentage of stormwater runoff on-site and tree protection laws. Bosomworth *et al*. (2012, VCCCAR) identified several examples from the USA including:

Development incentives One of the most effective ways of implementing GI is through integrated land development design, planning and policies, supported by incentives and regulations. For example, incentives might be offered to developers during the process of applying for development permits, such as: zoning upgrades, expedited permitting, reduced stormwater management requirements and increases in floor area. In other cases, GI might be mandated for particular types of development. These could be based on systems such as the Green Building Council of Australia's Greenstar rating, through provisions of special privileges for developers who implement green infrastructure with certification

Stormwater fee discounts For large new developments a stormwater management fee that is based on impervious surface area could be considered. If property developers reduce the need for stormwater infrastructure by reducing impervious area and the volume of runoff discharged from the property, the municipality(or in our case water authority) reduces the fee.

Grants, rebates and installation financing Provide direct funding, tax credits or reimbursements to property owners and/or community groups for implementing a range of green infrastructure projects and practices, including installation of specific practices in identified 'hotspots'.

Awards and recognition programs Provide marketing opportunities and public outreach for exemplary projects, which may include monetary awards.

FURTHER READING & REFERENCES

FURTHER READING

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