MULPHA

# URBAN COOLING
## DESIGN GUIDE

**Title** Urban Cooling Design Guide

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## ACKNOWLEDGEMENTS

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In addition we acknowledge previous applied projects in which HPA researchers have participated and from which we have drawn useful facts and figures, such as the Cooperative Research Centre for Low Carbon Living *Guide to Urban Cooling Strategies*, the Western Sydney Regional Organisation of Councils (WSROC) *Urban Heat Planning Toolkit*, City of Port Phillip *Cooling South Melbourne*, Victorian Department of Environment, Land, Water and Planning *Cooling your development: Guidelines for managing urban heat at the lot scale* and the Australian Capital Territory Government *Planning controls for living infrastructure and urban heat*.

## ACKNOWLEDGEMENT OF COUNTRY

We acknowledge the Bidjigal people of the Dharug nation, the traditional Custodians of the land upon which the Norwest development is located, and we pay our respects to the Elders past, present and emerging.



# CONTENTS

# GLOSSARY

**ALBEDO**
Another word for solar reflectivity or solar reflectance of a surface. The proportion of incident light reflected from a surface.

**ASPECT RATIO**
The ratio of average building height to street width of an urban canyon.

**BUILDING ENVELOPE**
Collective term for the building façades and roof. This serves to protect the indoor environment and ensure comfortable conditions with minimum energy consumption. The main components of the building envelope include the roof, walls, doors, and windows.

**COOL MATERIALS**
Materials with high albedo and/or high emissivity that stay cooler than conventional materials under solar radiation.

**HEATWAVE**
Three or more days of high maximum and minimum temperatures, which are unusual for a specific location.

**HEAT CAPACITY**
The ratio of the heat added to or removed from an object to the resulting temperature change.

**HEAT RESILIENCE**
The extent to which the built environment can support outdoor activities during heat stress conditions.

**HEAT STRESS**
Heat stress occurs when our body is unable to cool itself enough (e.g. through sweating) to maintain a healthy temperature.

**HEAT TRANSFER**
The transition of thermal energy from a hotter item to a cooler item. Classical transfer of energy occurs only through conduction, convection, radiation, or any combination of these.

**LAND SURFACE TEMPERATURE (LST)**
It is the radiative skin temperature of the land derived from solar radiation. A simplified definition would be how hot the horizontal surfaces of the Earth (natural and artificial) are in a particular location.

**LEAF AREA INDEX (LAI)**
Leaf area index is defined as the projected area of leaves over a unit of land. It is indicative of the amount and type of vegetation canopy coverage.

**MEAN RADIANT TEMPERATURE (MRT)**
The theoretical uniform surface temperature of an enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform enclosure.

**SKY VIEW FACTOR (SVF)**
The extent of sky observed from a point on the ground as a proportion of the total possible sky hemisphere.

**THERMAL COMFORT**
The state of mind that expresses satisfaction with the thermal environment. This is commonly evaluated subjectively through surveys or interviews.

**THERMAL CONDUCTIVITY**
The amount of heat per unit time per unit area which can be conducted through a plate of unit thickness of a given material.

**THERMAL EMISSIVITY**
Emissivity (or emittance) is the ratio of the heat emitted from an object or surface to that of a standard "black body".

**TREE CANOPY**
In ecology, tree canopy refers to the upper layer or habitat zone, formed by the tree crowns (not to be confused with urban canopy layer, see later in this glossary). Sometimes the term is used to refer to the extent of the outer layer of leaves of an individual tree or group of trees.

**UNIVERSAL THERMAL CLIMATE INDEX (UTCI)**
This is an index that quantifies outdoor thermal comfort by integrating personal parameters (human activity and clothing insulation) and four thermalphysiological factors: ambient temperature, mean radiant temperature, relative humidity and wind speed.

**URBAN BOUNDARY LAYER**
That part of the atmosphere whose characteristics are affected by the presence of an urban area at its lower boundary.

**URBAN CANOPY LAYER**
The layer of air in the urban atmosphere beneath the mean height of the buildings and trees.

**URBAN CANYON**
The space above the street and between the buildings on either side of the street.

**URBAN FABRIC**
A generic term that describes the physical composition of cities including building types, paved areas, tree cover, and open space.

**URBAN HEAT ISLAND (UHI)**
The phenomenon whereby the trapping of solar radiation and release of anthropogenic waste heat leads to higher temperatures in urban areas compared to their rural surroundings.

# INTRODUCTION

## BACKGROUND

Mulpha Norwest is a wholly owned subsidiary of Mulpha Australia Pty Limited, which acquires, develops and manages a range of property and lifestyle investments. These include Hayman Island, Intercontinental Hotel Sydney, Sanctuary Cove Resort and Bimbadgen winery.

As well as developing the master planned communities of Bella Vista in the Hills District and Mulgoa Rise in Western Sydney, Mulpha Australia is transforming the 377-hectare Norwest Business Park into a world-leading innovation, lifestyle and economic hub, with all the features of a 'Smart City'.

Norwest Business Park comprises 180 hectares of business land, 151 of residential land and 46 hectares of waterways, walking trails and parks, including the historic Bella Vista Farm Park. Norwest is one of Australia's largest and most successful business parks, home to 30,000 workers across 800 businesses and 6,000 residents. The 377 hectare estate is located at Baulkham Hills and represents an investment in excess of $2.5 billion.

**Mulpha has set the following objectives for the project:**

1. 2°C reduction in ambient temperature of Norwest
2. Reduced cost to business through reduction in cooling energy requirements
3. Increased resilience for business and the health of residents
4. Engagement with the community on urban cooling

Mulpha has partnered with the University of New South Wales Built Environment School High Performance Architecture team to deliver a practical research program which will enable significant cost savings and health benefits to the businesses and residents of Norwest.

Sanctuary Cove Resort

The program includes establishment of a network of environmental sensors around the precinct and associated data collection, analysis and mapping, and development of an evidence-based design guide (this document) to create a more liveable environment and deal with the challenge of climate change at the local level.

### WHO SHOULD USE THIS GUIDE?

This practical guide is designed to assist developers, design practitioners and builders to understand urban overheating and to introduce suitable cooling strategies in the early stages of planning and design to improve the performance of a particular development, and in the long run to benefit the wider neighbourhood.

It draws on the evidence base behind the publication of the Cooperative Research Centre for Low Carbon Living *Guide to Urban Cooling Strategies* and more recent urban cooling research conducted in Western Sydney, Victoria and the ACT by members of the UNSW team.

### HOW TO USE THIS GUIDE

This guide is structured into ten key sections designed to help you develop an urban heat response for your own development site. The table below provides more information on how to navigate the guide, and the types of questions to consider when preparing an urban heat response for your project. If you see words or terms you do not understand, please refer to the Glossary on page 5.

**Why should I adopt an urban heat response for my development site?**

**SECTION 2:** Overview of urban overheating

**SECTION 3:** Benefits of adopting a cooling strategy

*"The benefits and co-benefits of adopting cooling design measures for your project are significant, adding value and improving the aesthetics and function of a development."*

**Which combination of cooling design measures are available?**

**SECTION 4:** Design principles for urban heat resilience

**SECTION 5:** Design considerations at the early development stage

**SECTION 6:** Cooling toolkit

*"A cooling toolkit provides explanations of each cooling design measure, its associated cooling benefits, different methods and recommendations for optimal application and an indicative upfront cost."*

**How do I cope with extreme heat waves?**

**SECTION 7:** Further design responses to heatwaves, health and urban cooling

*"Given the increasing prevalence, intensity and duration of extreme heat events over the past two decades and future climate change projections, further information relating to heatwave conditions and measures to achieve night-time cooling to support health and wellbeing is necessary."*

**How do I develop an urban heat response for my development from scratch?**

**SECTION 8:** Some rules of thumb

**SECTION 9:** Development typologies

**SECTION 10:** Supporting information

*"Whenever possible, outdoor cooling strategies should be integrated into the decision-making process right from the initial stages of urban design and iterated with the design process."*

# OVERVIEW OF URBAN OVERHEATING

## SYDNEY'S CLIMATE AND WESTERN SYDNEY CHALLENGE

### Sydney is hot and getting hotter

Sydney has experienced a steady increase in temperature since the middle of last century, and in recent decades this process has accelerated. According to the NSW and ACT Regional Climate Modelling (NARCliM) initiative, Sydney is expected to experience an increase in average, maximum and minimum temperature for all seasons in the future, reflecting the broader phenomenon of global warming.

- **Maximum temperatures are projected to increase by 0.7°C for 2020-2039 and up to 1.9°C by 2060-2079.** The rise in maximum temperatures in turn will increase the number of heatwave events.
- **Minimum temperatures are projected to increase by 0.6°C for 2020-2039 and up to 2°C by 2060-2079.** This increase in overnight temperatures means not just fewer cold nights, but less relief from excessively hot days.

The NARCliM modelling also predicts an increase in the number of hot days per year. On average, the Metropolitan Sydney Region is expected to experience around 5 days above 35°C every year for 2020-2039, increasing to more than 10 hot days per year by 2070 (NSW OEH 2014).

### Sydney's Northwest is particularly exposed to heat

From Figure 1A. and 1B. we can see that the Sydney region experiences large variations in temperature between the coast, Western Sydney and the Blue Mountains. The North-western Sydney region is projected to experience 10-20 hot (>35°C) days per year in the 2060-2079 period, triple the number of hot days per year in the eastern Sydney region (NSW OEH 2014). Several factors are involved.

- **Geography and weather patterns intensify the urban heat island (UHI) in the Northwest.** Wind tends to be calmer in western Sydney, and the region is less frequently cooled by easterly sea breezes (Figure 2. on pg. 10).
- **Urbanisation is having a significant effect in Sydney's Northwest.** Ongoing urbanisation and densification are other factors which will contribute to increased urban heat over the coming decades. According to on-site inspections carried out by the UNSW team, the Norwest area has a slightly lower urban density and higher vegetation fraction compared to the heavily urbanised eastern part of Sydney (Figure 3. on pg. 10). However, much of Western Sydney's continuing development involves conversion of vegetation cover to built-up areas; it is projected that "urban development of forests and grasslands in Western Sydney may increase temperatures in 2030 by a similar [additional] amount to the changes occurring from climate change" (Adams et al., 2015 pg. 24).

The land cover of built-up areas, including roofs and walls, roads and parking lots, industrial and commercial sites is impermeable and characterised by low albedo (reflectivity) and high absorption of heat.

Thermal mapping (Figure 3. on pg. 10) shows that the surface temperatures of building envelopes and exposed parking lots are significantly higher than green and blue infrastructure - vegetation and water bodies. High surface temperature can directly influence the surrounding air temperature and create an uncomfortable thermal environment for residents.

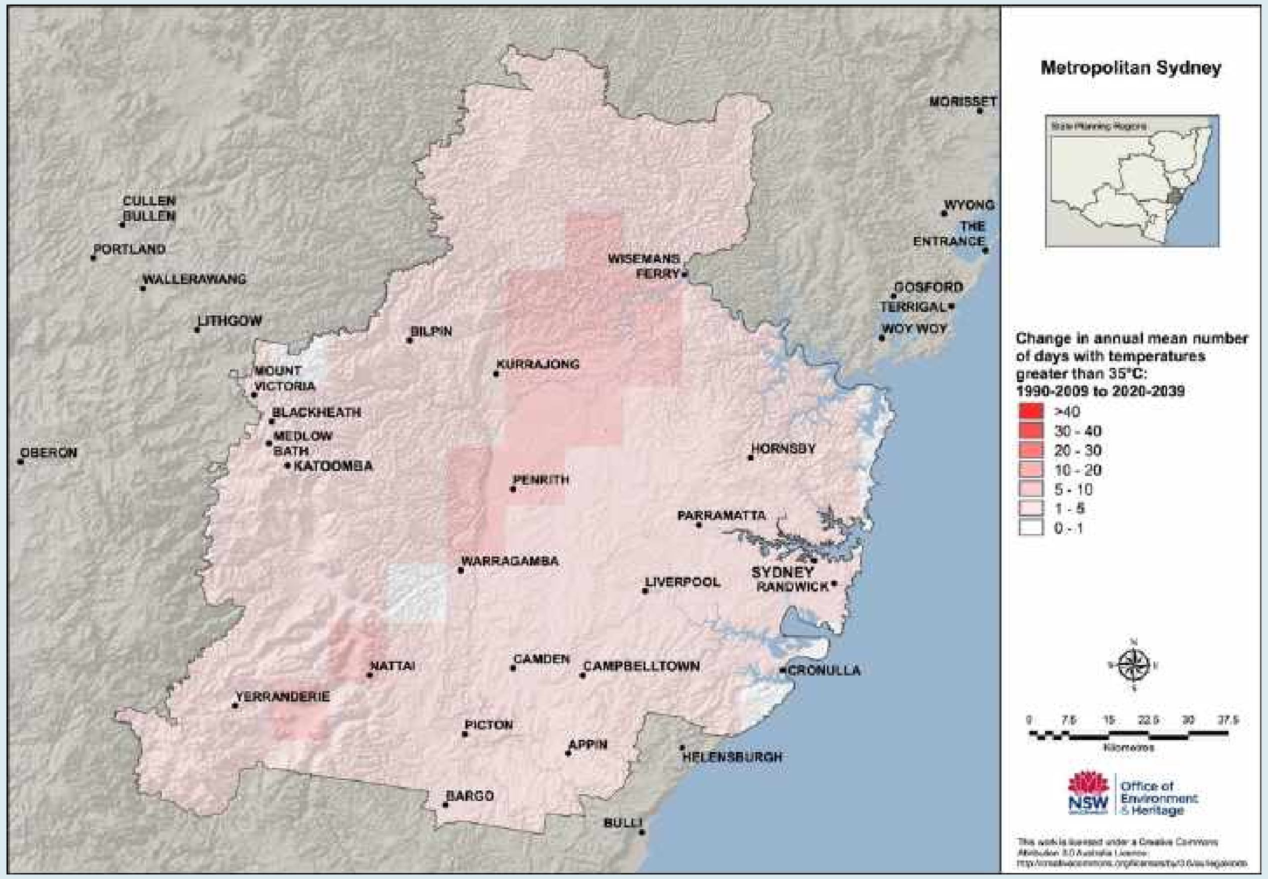



**Figure 1A.** Near future (2020–2039) projected changes in the number of days per year with maximum temperatures above 35°C (NSW OEH 2014).

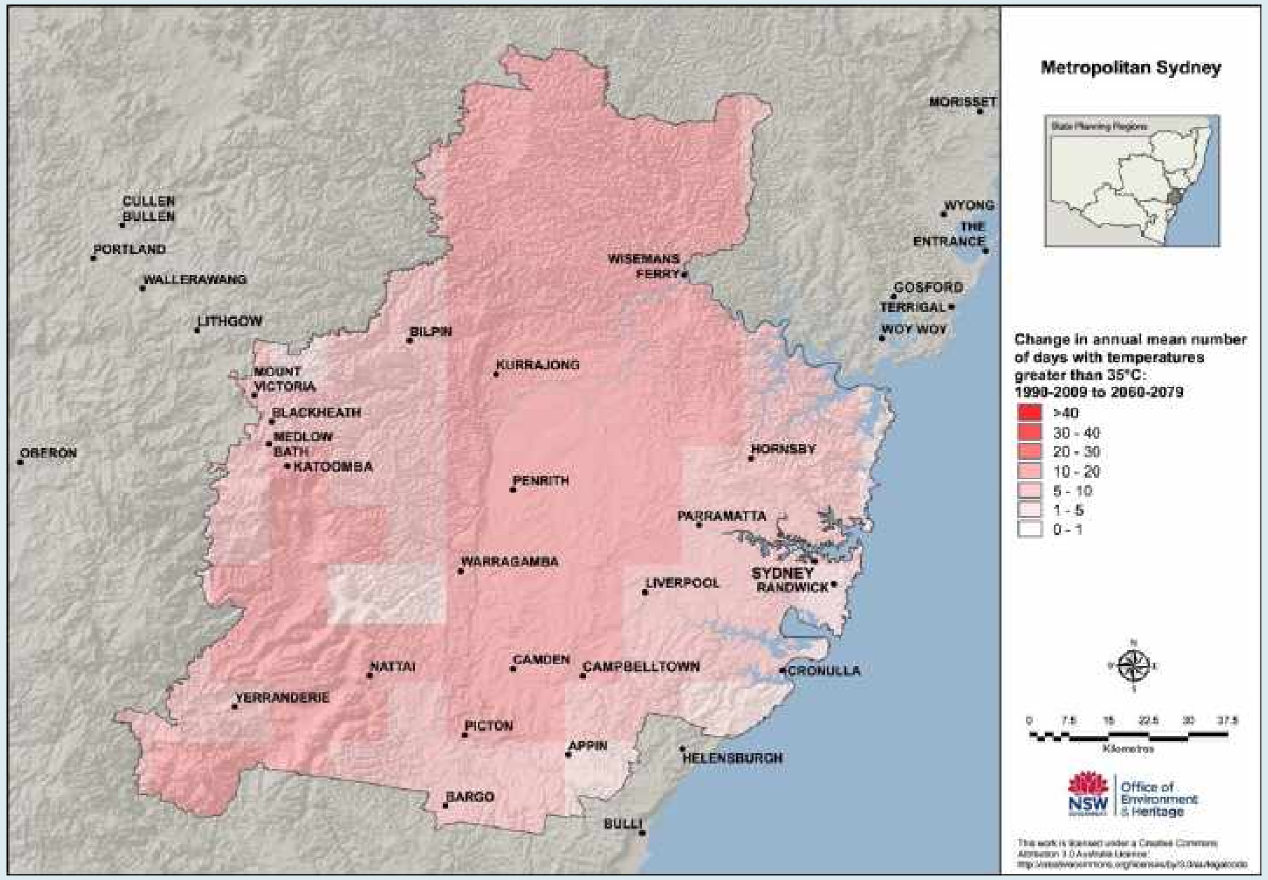



**Figure 1B.** Medium future (2060–2079) projected changes in the number of days per year with maximum temperatures above 35°C (NSW OEH 2014).

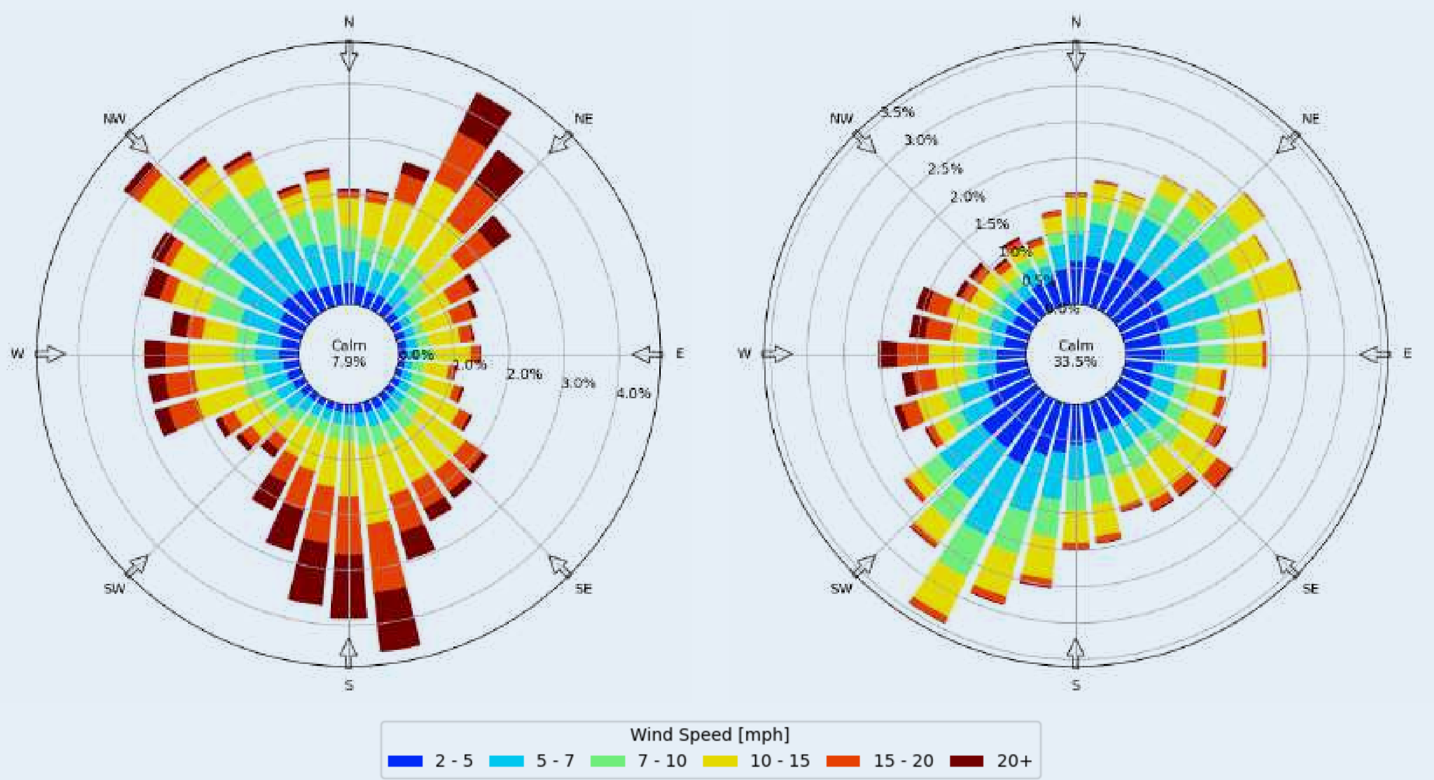



**Figure 2.** Wind roses for Sydney Airport (left) and Richmond Airforce Base (right) representing coastal and western Sydney respectively, from weatherbase.com. Note that wind speed is in miles per hour. The Australian Bureau of Meteorology offers the following guide to wind roses: Each branch represents wind coming from that direction. The branches are divided into segments of different thickness and colour, representing wind speed ranges from that direction. The length of each segment within a branch is proportional to the frequency of winds blowing within the corresponding range of speeds from that direction.

**Figure 3.** Drone thermal imaging of Norwest, retrieved from norwestcity.com.au/vision/initiatives/norwesteco/heatmap

# MULTIPLE IMPACTS OF URBAN HEAT

## HEAT RELATED MORTALITY, MORBIDITY AND HUMAN WELLBEING

Human beings adjust heat production and dissipation in response to temperatures through the mechanisms of vasoconstriction and vasodilation (narrowing and widening of blood vessels), shivering and sweating to maintain a relatively constant core temperature (Hensel and Schafer, 1984). But the ability to physiologically adapt to heat stress comes with a limit, beyond which can endanger health. Australian studies have found that heatwaves contribute to significant surges in mortality, ambulance emergency caseloads and GP home visits for heat-related conditions (Tait et al., 2018) (see figure 4. below). Under the most extreme greenhouse gas emission scenario, heatwave-related mortality across Sydney will increase by 471% in the period 2031–2080 compared with 1971–2010 (Guo et al., 2018).

Cool outdoor spaces are essential for community wellbeing. Places like town centres, public transport stops, bike lanes and footpaths are essential for day-to-day life. Urban overheating can dissuade citizens from engaging in outdoor activities, and the resulting sedentary lifestyle negatively impacts health, increasing the risk of cardiovascular diseases, diabetes, and obesity (Rao et al., 2007).

## ENERGY AND WATER DEMAND

Global warming and urban overheating increase the temperature of cities and exacerbate water and energy demand. Statistical analysis demonstrates that a 1° Fahrenheit (0.56°C) increase in daily low temperature increases the monthly water use by 290 gallons (1100 litres) for a typical single-family unit (Guhathakurta and Patricia). The urban heat island effect is also associated with a 13.1% increment of cooling energy demand for an individual building in an urban area compared with the surrounding rural reference stations (Santamouris, 2014). In return, higher energy demand – for example, for air conditioning – inevitably results in more waste heat production, thus adding to thermal discomfort.

## ECONOMY AND PRODUCTIVITY

Urban heat stress also has a negative impact on productivity, reducing physical work capacity, cognitive and motor performance (Ebi et al., 2021). Workplace heat stress is projected to account for an annual loss of $6.9 billion in Australia due to reduced productivity (Zander et al., 2015). Furthermore, relatively higher overnight temperatures may also affect people's biophysical recovery capacity after work and further reduce work productivity on the following day (Day et al.,2019).

## IMPACTS ON URBAN INFRASTRUCTURE

The increased use of air conditioners during heatwaves places the electricity grid system under great stress as well as adding to the external heat load.

Santamouris et al. (2017b) found that peak energy demand almost doubled when temperatures increased from 20 to 40°C. Meanwhile, the electricity infrastructure, including generators and transmission lines are more likely to be impaired by the heavy load, which in the worst-case scenario, may be compounded by bushfires (Australian Energy Council & Energy Networks Australia, 2020). Power outages can of course affect other urban infrastructure that relies on the electricity grid.

**6% higher heat-related mortality risks**
for residents living in warm neighbourhoods

**100% increase in peak electricity demand**
when temps increase from 20°C to 40°C

**Unmeasured impacts on flora and fauna**
Mass deaths of flying foxes are one indicator of the scale of this impact

**$6.9 Billion in lost productivity**
due to heat stress, annually across Australia

**Figure 4.** Heatwave impacts in Australia (WSROC, 2021)

# BENEFITS OF ADOPTING A COOLING STRATEGY

ADOPTING COOLING STRATEGIES CAN GENERATE A SERIES OF SOCIAL, FINANCIAL AND HEALTH BENEFITS OVER THE LIFETIME OF AN INDIVIDUAL BUILDING DEVELOPMENT, AND HAS THE POTENTIAL TO MITIGATE URBAN OVERHEATING WHEN APPLIED ON LARGE SCALE.

The importance of mitigation interventions is highlighted by research which indicates major impacts of urban overheating on overall energy consumption and associated costs (around 4.1% per degree of temperature increase); concentration of harmful pollutants; and heat-related morbidity and mortality (a 2°C rise in maximum temperature is associated with average 5.3% increase in excess deaths). Moreover, the co-benefits of cooling interventions extend well beyond cooling effects.

## COOLING EFFECTS

### Residential

- Improve the thermal comfort of private and communal spaces such as backyards, courtyards and gardens, and thereby increase their attractiveness and usage.
- Improve the walkability of residential areas despite hot weather, contributing to residents' health and wellbeing.
- Decease night-time temperature, increasing residents' sleep quality and reducing stress.
- Contribute to lowering indoor temperatures, thereby allowing natural ventilation, decreasing demand for air conditioning and reducing energy consumption.

### Commercial and Industrial

- Reduce the heat stress in outdoor car parks and loading areas, keeping vehicles, machinery and outdoor workers cooler.
- Improve staff productivity by providing them with cooler outdoor rest and lunch spaces.
- Increase the attractiveness of corporate/semi-public open spaces by improving outdoor thermal comfort.
- Improve the economic performance for street-level retail by enhancing the customer and visitor experience on hot days.
- Reduce health risks for vulnerable customers, visitors and staff.
- Decrease night-time temperature, improving the thermal comfort for night shift staff.
- Reduce the cost spent on air conditioning system operation, by reducing average and peak electricity demand.

## IMPROVED PROPERTY VALUE

Studies have consistently found that buyers are willing to pay more for the houses with more tree cover, or on a leafier street. For example, a recent meta-analysis of 37 "willingness-to-pay" studies from around the globe estimated increases in local property values of up to 20% when compared with properties unaffected by greening interventions (Bockarjova et al., 2020).

## NOISE REDUCTION

Green infrastructure can reduce noise pollution in urban environments, as vegetation absorbs, scatters and influences the reflection of airborne sound (Dimitrijevi et al., 2017).

## WATER MANAGEMENT

Stormwater runoff is an increasing problem in urban areas due to the replacement of pervious surfaces by hard impervious surfaces with no water retention capacity. Since incident rainwater drains directly to the stormwater sewerage system, stormwater drains can be overwhelmed under heavy rainfall, causing flash flooding, especially in low-lying urban areas. Green infrastructure and permeable surfaces can help mitigate stormwater runoff due to their capacity to retain and infiltrate water (Manso et al., 2021).

## AIR QUALITY IMPROVEMENT

Green infrastructure can also contribute to air pollutant removal and improved air quality (Abhijith et al., 2017), particularly relevant given that hotter temperatures exacerbate air pollution.

## BIODIVERSITY ENHANCEMENT

Establishment of green infrastructure with selection of suitable plant species, especially those native to the location, offers a way to protect and enhance local biodiversity (see also 'Urban Green Infrastructure' on pg. 21). A biodiverse landscape attracts a variety of birds, small mammals, frogs and lizards, pollinating insects and more. Biodiversity also makes for a more resilient environment, better able to deal with the challenges of climate change.

Moreover, while nature loss poses a major risk to businesses, moving to nature-positive investments provides significant opportunities The Taskforce on Nature-related Financial Disclosures is a new global initiative set up in 2021 which represents financial and related businesses with nearly $US 20 trillion in assets. The market-led, science-based TNFD framework has been designed to enable businesses to integrate nature into decision – the beta version is available at: framework.tnfd.global

ESTABLISHMENT OF GREEN INFRASTRUCTURE WITH SELECTION OF SUITABLE PLANT SPECIES

# DESIGN PRINCIPLES FOR URBAN HEAT RESILIENCE

## The fundamental principles of heat transfer stay the same from human to urban scale.

**Convection** is the transfer of heat by the movement of fluids (including air) and can be accelerated by increasing the air speed. Evaporation of sweat from the human skin surface, or water from leaf surfaces, also benefit from increasing air speed, but at the same time this can be attenuated by high humidity.

**Radiation** in the urban environment includes shortwave solar radiation and longwave infrared radiation emitted from surrounding surfaces. Radiant heat sources can be modified by surface absorptivity and reflectivity.

**Conductive** heat transfer from a hotter surface to a cooler one occurs through solid materials, such as building roofs, walls, and floors. The rate of heat conduction is determined by the insulation properties and the thickness of the material layers (Jay et al., 2021). Figure 5. below shows heat transfer principles as applicable at urban, building and individual human scale, explained further in the text.

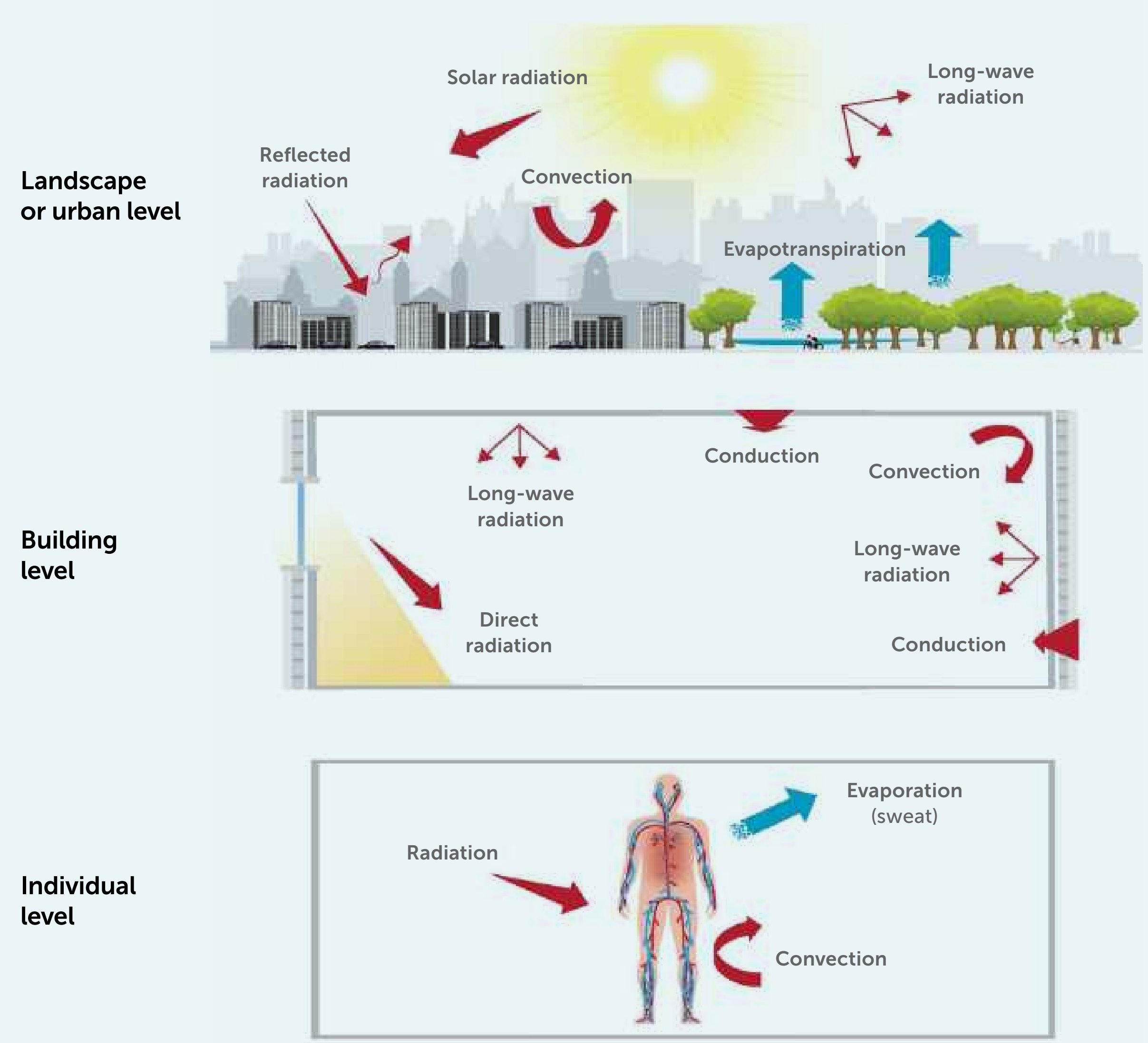



**Figure 5.** Heat transfer at urban, building and human level Reprinted from The Lancet, 398, Jay, O. et al. Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities, pp 709-724. Copyright (2021) with permission from Elsevier.

### REDUCING HEAT (URBAN SCALE)

The urban heat island effect refers to the difference between temperatures in the city vs. the surrounding countryside.

At city scale, solar radiation is absorbed and re-radiated by massive urban structures; the increasing number of tall buildings gives rise to a complex urban morphology, which slows wind speed and reduces convective heat removal.

Together with anthropogenic waste heat (released from vehicles, power plants, building HVAC systems and other heat sources) heat becomes trapped in the urban canyon due to limited sky view for the longwave radiation to escape. Urban areas also possess less vegetation and water bodies due to typical land uses, which reduces evaporative and convective heat losses (Kershaw et al., 2018).

Typical cooling design interventions at the urban scale include measures to:

- Increase wind speed
- Reduce ambient air temperature
- Increase evapotranspiration
- Increase shading
- Use construction materials with greater reflectance and less heat storage capacity

### ADAPTING TO A HOTTER CLIMATE (LOCAL/ BUILDING/PEDESTRIAN SCALE)

#### Cool buildings

Heat transfers to the indoor environment through windows by radiation, through walls and roofs by conduction and through openings by convection.

The temperature of external building envelopes is determined by orientation, shading from adjacent built structures and vegetation, building material properties such as reflectivity, conductivity and heat capacity, and any convective and evaporative heat losses, for example from prevailing winds. In addition to these passive design properties, air conditioning systems also play an important role in keeping internal spaces cool, especially during heatwaves.

Typical cooling design interventions at the building scale include measures to:

- Reduce direct solar radiation
- Reduce heat transfer through walls and roofs – this can include insulation, and also cool (high albedo) roofs and walls to reflect incident solar radiation (see also 'Cool building envelopes / cool roofs' on pg. 29)
- Increase ventilation

#### Cool outdoor spaces (cool pedestrians)

Heat transfer between a human body and the surrounding environment mainly involves radiation and convection. When people encounter a different thermal condition, the heat transfer between the surrounding environment and the body surface changes the skin temperature, and the temperature gradient between the skin and the interior of the body passively promotes heat transfer. Being warm-blooded, human beings as noted above can adjust heat production and dissipation to maintain a relatively constant core temperature, within limits (Hensel and Schafer, 1984).

Well implemented outdoor cooling strategies can have a direct and significant effect on improving the microclimate, which is directly experienced by the users. For example, the thermal perception of the microclimate under tree shade will be different from nearby paved open spaces.

The former might encourage citizens to engage in outdoor activities even on hot summer days, while the latter is very likely to be identified as a hot spot to be avoided by pedestrians.

Typical cooling design interventions for outdoor spaces include measures to:

- Reduce direct solar radiation
- Reduce reflected radiation from façades and pavements
- Reduce ambient air temperature
- Increase wind speed

## URBAN COOLING METRICS

### Air temperature

Air temperatures are useful when assessing the thermal environment at a city or neighbourhood scale. They can be directly measured using a thermometer, which is cheap, easy to operate, and provides reliable readings under different weather conditions; or measured using remote sensing techniques, such as thermal imagers. The number of hot days (with daily maximum air temperature higher than 35°C) has been widely used for measuring the intensity of heatwaves.

Previous studies have identified the incidence of heat-related mortality and morbidity increases with prolonged hot days, especially among vulnerable population groups such as children, elderly, the disabled or those with a pre-existing medical condition.

### Human thermal comfort and thermal comfort index

At the microscale, the impacts of cooling strategies can be seen through the lens of human thermal comfort, which is not only affected by the air temperature.

Fanger (1970) first postulated that the six most important variables influencing the condition of thermal comfort were: activity level, clothing resistance, air temperature, mean radiant temperature, relative air velocity, and relative humidity and we need to consider their combined effect on the human body. The thermal comfort model was designed to mathematically describe the heat transfer between the environment and the human body, plus heat transfer and thermal regulation inside the body.

Using a thermal comfort index allows us to predict thermal perception within a given environment. Among a variety of available thermal comfort metrics, the Universal Thermal Comfort Index (UTCI, Figure 6. overleaf) is one of the most commonly used indices for measuring heat stress in outdoor spaces.

Figure 7. overleaf demonstrates that the difference between built-up areas and natural land covers can be as high as 8°C. Compact low-rise, large low-rise and heavy-industry urban areas experience 'Moderate Heat Stress' on an average summer day while most of the sparsely built and open low-rise areas are consistently in 'No Thermal Stress' zones. The difference emphasises the importance of introducing cooling strategies to these vulnerable urban areas.

Researchers from UNSW and the University of Sydney (Sadeghi et al. 2021) recently developed a Heat Stress Exposure metric which combines the duration and intensity dimensions of heat exposure.

Assuming a threshold of 26°C for moderate heat stress, cumulative exceedances of this threshold throughout the year (UTCI, in units of degree hours (°C.hr)) gave rise to figures of 4000 to 6000°C.hr for Sydney's western suburbs, more than twice the heat stress exposure of coastal eastern Sydney.

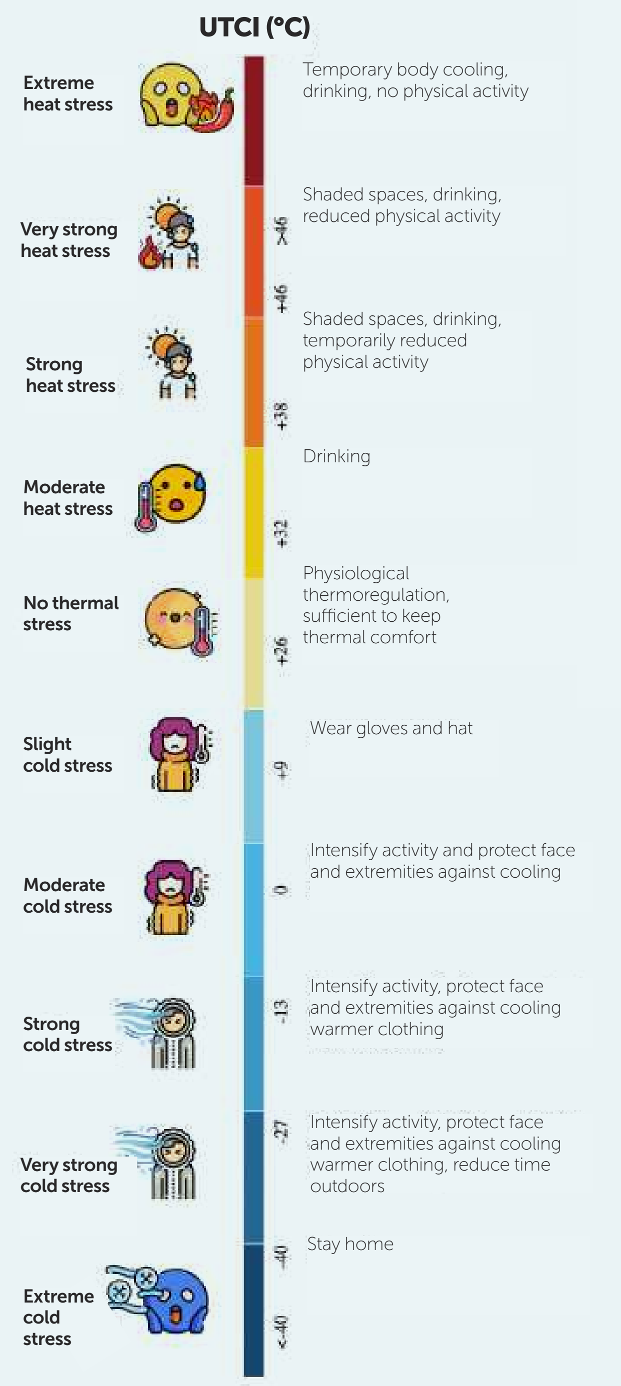



**Figure 6.** UTCI thermal comfort index, retrieved from dazzling-bhabha-b4d8f4.netlify.app

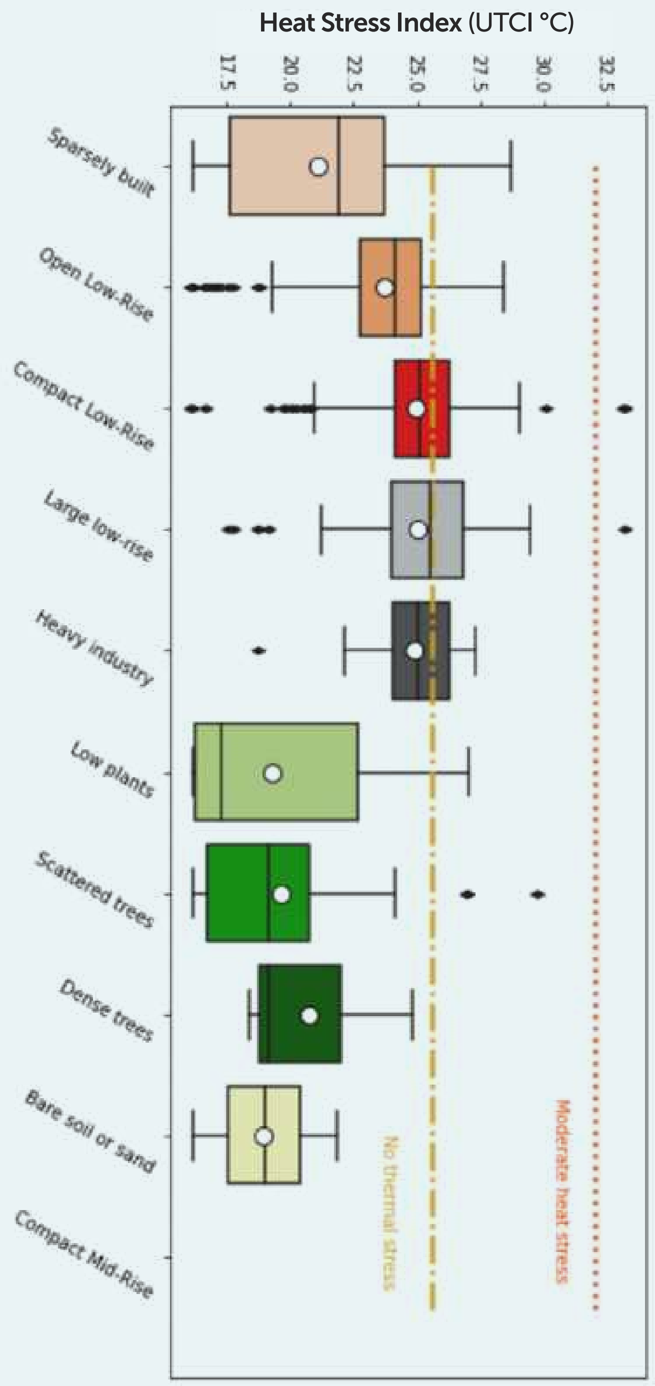



**Figure 7.** UTCI at 2 pm of an average summer day in Norwest and Bella Vista based on their climate zones, retrieved from storymaps.arcgis.com/stories/0410bd52083a4274aee3d3679d510efe

# DESIGN CONSIDERATION AT EARLY DEVELOPMENT STAGE

Some elements should be considered during the first phase of the planning of a new development, since they either cannot be accommodated through retrofitting, or would be very costly to incorporate.

A useful 'rule of thumb' is that 90% of a project's budget is locked in after just 10% of design time. In the early development stage, the effort should be placed on optimising the wind path, shading and placement of green open space.

### WIND PATHS

The microclimate within the urban canopy layer is dominated by the characteristics of the immediate surroundings. It is important to check the closest meteorological station for a localised wind rose in different seasons. Strategies include (Figure 8. below):

- Aligning streets in parallel or up to 30° to the summer season prevailing wind direction to maximise the penetration of wind through the district.
- Widening the streets oriented along the prevailing wind direction, and shortening the length of the street grid perpendicular to the prevailing wind direction to minimise stagnation.
- Aligning the longer frontage of building plots parallel to the wind direction and introducing non-built areas and setbacks.
- Stepping building heights in rows to encourage the flow of wind at higher levels and to avoid obstruction of the breezeway (Ruefenacht and Acero, 2017).
- Adopting a terraced podium design can direct downward airflow and help enhance the air movement at the pedestrian level (Ruefenacht and Acero, 2017).

### SHADING

Optimised building orientation can lower sun exposure and therefore minimise solar heat gains through the façades.

- Building orientation should facilitate solar access during the winter season, and should allow more space to the north and northwest for shading structures to maximise cooling benefits in summer.
- When developing a site with multiple buildings, an ideal arrangement is to have the long axis of buildings oriented east-west, and to provide sufficient shading to the north and west facing building façades (Figure 9.).
- In relation to sun path, sufficient shading structure should be provided to east-west oriented streets and street segments that cannot be protected by building shade during summer.
- Meanwhile, it is also important to avoid undesirable overshadowing from tall buildings which may dominate for too many hours of the day in narrow streets, limiting solar access to spaces and buildings where it is desirable.

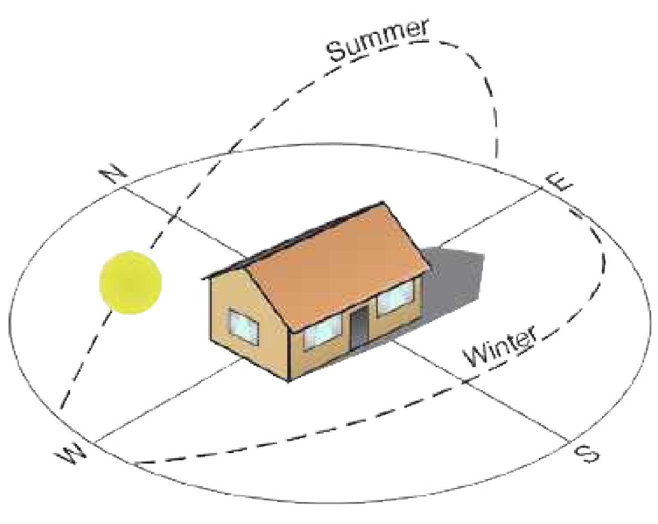



**Figure 9.** Ideal orientation of building (retrieved from nachi.org/building-orientation-optimum-energy.htm

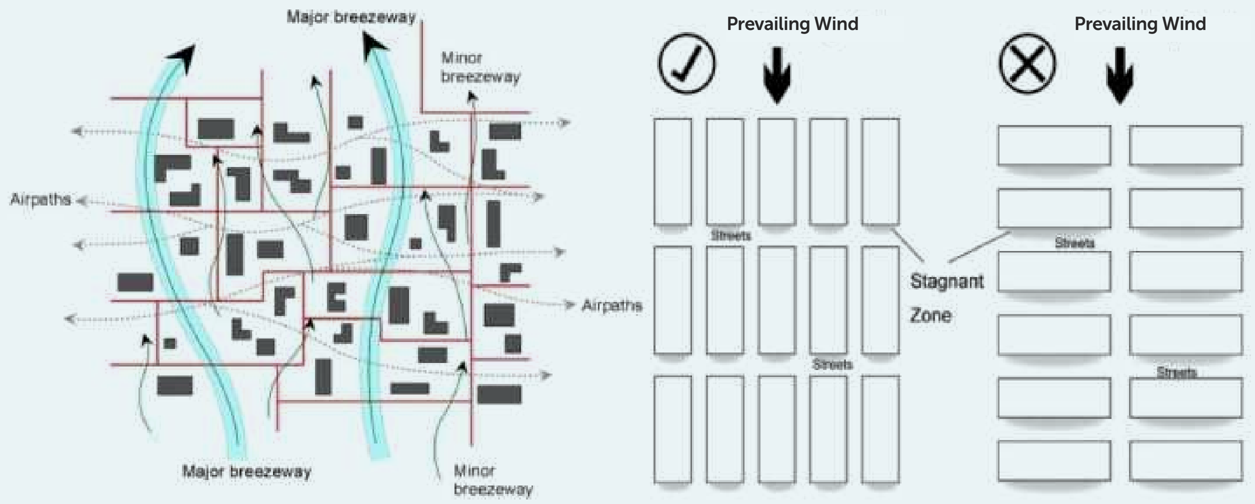



**Figure 8.** Urban breezeways (left) and orientation of street grids (right) Reprinted from Building and Environment, 44, Ng, E. Policies and technical guidelines for urban planning of high-density cities–air ventilation assessment (AVA) of Hong Kong, pp 1478-1488. Copyright (2009) with permission from Elsevier.

OPTIMISED BUILDING ORIENTATION CAN LOWER SUN EXPOSURE AND MINIMISE SOLAR HEAT GAINS.

## GREEN OPEN SPACE PLACEMENT

The placement of greenery is not only related to a development site's internal unbuilt areas such as potential pocket parks, but also relates to larger development projects which may incorporate more substantial area(s) of green space (Figure 10. below).

- Green open spaces should be prioritised for locations upwind of target areas, such as local hotspots and communities with vulnerable populations, for better distributing cooled air downwind. The higher the elevation of the green space, the easier it is for the cool airflow to stream downhill.
- The type, arrangement and coverage of vegetation should be adapted to the activities and time of the day the park and open spaces are used. For example, in parks adjacent to commercial, retail and entertainment areas where cooling during the day is more important, it is preferable to adopt larger trees for extensive shading. In contrast, residential zone parks should support night-time cooling, so lawns/ground covers with larger sky view factor (SVF) may be more effective.

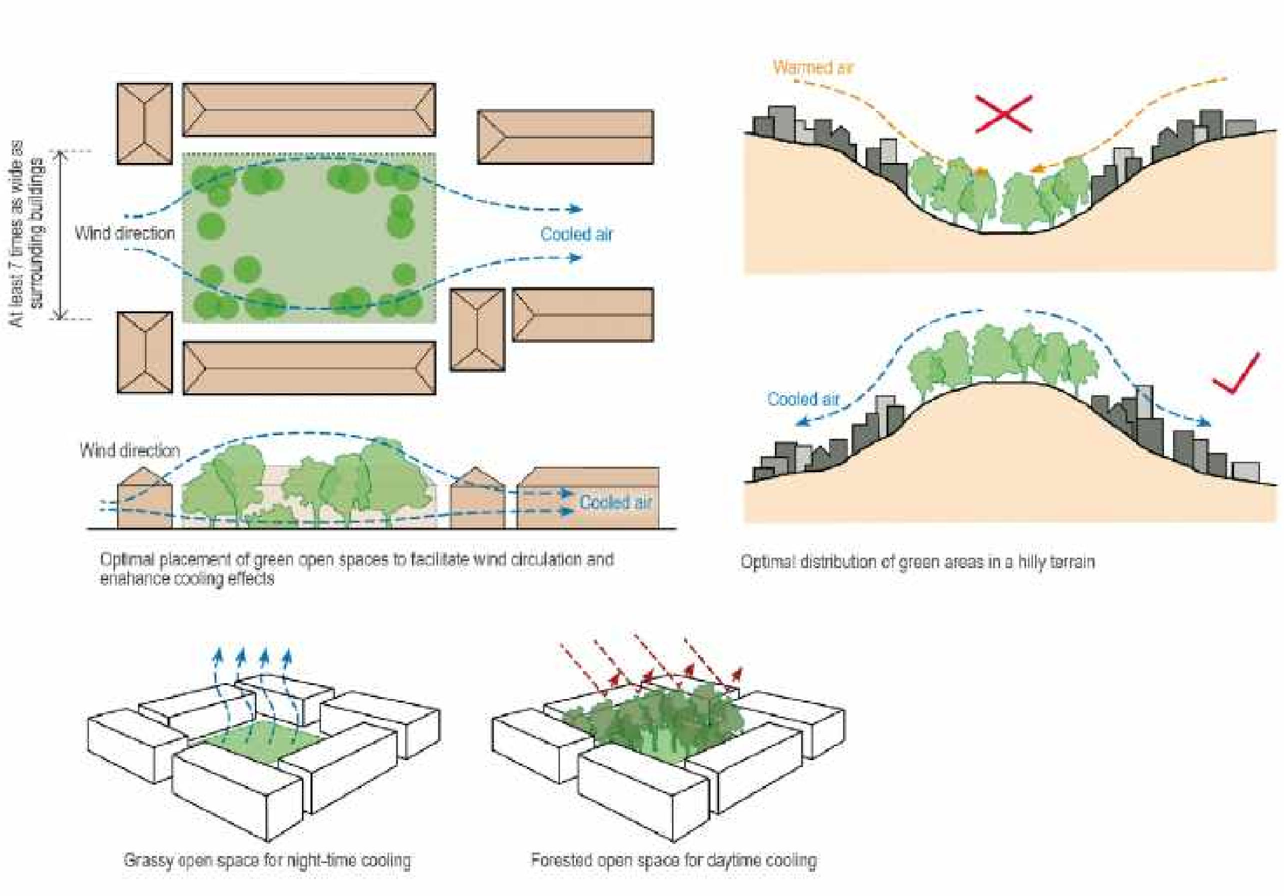



Figure 10. Recommendations for the location of greenspaces (DELWP, 2020).

# COOLING TOOLKIT

## URBAN GREEN INFRASTRUCTURE

### Trees

#### HOW IT WORKS / BENEFITS OF TREE CANOPY COVER

Trees can provide cooling in three ways: by providing shade, through evapotranspiration, and by channelling cooling breezes and blocking hot winds (Figure 11. below and Figure 12. on pg. 23). For pedestrians, the shading provided by trees plays a role in maintaining outdoor thermal comfort during hot sunny days.

Trees block the solar radiation and use the energy for growth and driving evapotranspiration from their leaves, reducing canopy temperatures and preventing warming of the surrounding air. Compared with shallow rooting grasses and shrubs, trees use their deep roots to draw up infiltrating rainwater and helping to reduce the volume of stormwater runoff.

In addition to cooling, trees take up and store carbon dioxide, help improve air quality, support biodiversity and provide amenity and recreational benefits (McPherson et al., 2005). Views of and interaction with urban greenery relieves stress, enhances wellbeing and can even improve workplace productivity (Navarrete-Hernandez and Laffan, 2019).

#### HOW TO IMPLEMENT

It is important to provide adequate soil volume and to select and appropriately locate suitable species to avoid roots or branches interfering with above- and below-ground utilities and building footings.

Well-irrigated greenery provides more effective cooling throughout the day compared to dry plants and bare soils. To ensure the growth and vitality of trees and their cooling performance in terms of evapotranspiration and shading, adequate soil moisture (meaning regular irrigation) must be ensured.

This can be facilitated by installing soil moisture sensors, for example: metergroup.com/environment/articles/which-soil-sensor-is-perfect-for-you/.

The selection and installation of trees should be climate and site-specific. Factors that need to be considered include land uses, street width and orientation, building heights and level of pedestrian activity (Ding et al., 2019).

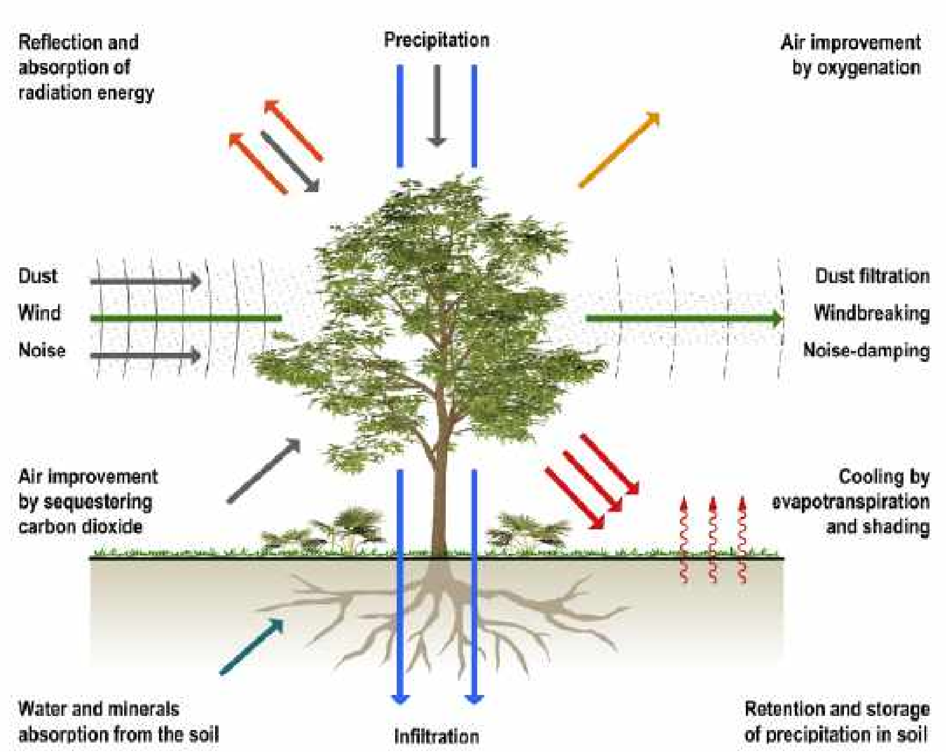



Figure 11. Schematic of the climate-related benefits provided by trees to the built environment (DELWP, 2020; Bartesaghi Koc, 2018).

**Table 1.** Guidelines for targeted street-scale tree arrangement (Coutts and Tapper, 2017)

| FACTORS FOR CONSIDERATION | ADVICE | WHY |
|---|---|---|
| **Street width** | Target those streets with a low aspect ratio (building height to (street width) | Wide open streets are less likely to be shaded by the surrounding buildings shade, and are exposed to greater amounts of solar radiation. |
| **Street orientation** | Target east west oriented streets | East-west oriented streets are exposed to more solar radiation compared with north-south oriented streets, where streets and footpaths are partly shaded by buildings in the morning and afternoon. |
| **Street sides** | For east-west oriented streets, target the southern side of streets. | North facing walls are exposed to solar radiation throughout the day and west facing walls are exposed to greater solar radiation at the hottest time of day. |
| **Tree grouping** | Gather the trees together in groups. | Clustered trees have a greater cooling potential for the microenvironment under the tree canopy and are less susceptible to water stress. |
| **Tree spacing** | Intersperse tree clusters with open spaces. | The open spaces between tree clusters allow for surface cooling and ventilation at night. |

## TREE PLACEMENT

The table above provides specific guidance on how to optimise tree planting for the maximum air temperature reductions and outdoor thermal comfort improvement (Thom et al., 2016).

## TREE SELECTION

Tree canopy density (represented by leaf area index, the ratio of leaf area to the ground area directly below the canopy) has been identified as a key factor for assessing canopy performance.

Therefore, the ideal planting scheme should prioritise trees with higher canopy density, and / or clustering of tree species with different heights to create multi-layer canopies. Other key factors which contribute to air temperature reduction are vertical leaf area densities, leaf colour and thickness (Mohammad et al., 2020).

A list of recommended tree species suitable to support urban cooling is set out in the 'Supporting Information' section on pg. 49.

The ecological community relevant to Norwest is known as Cumberland Plain Woodland, which has been listed as Critically Endangered under the Threatened Species

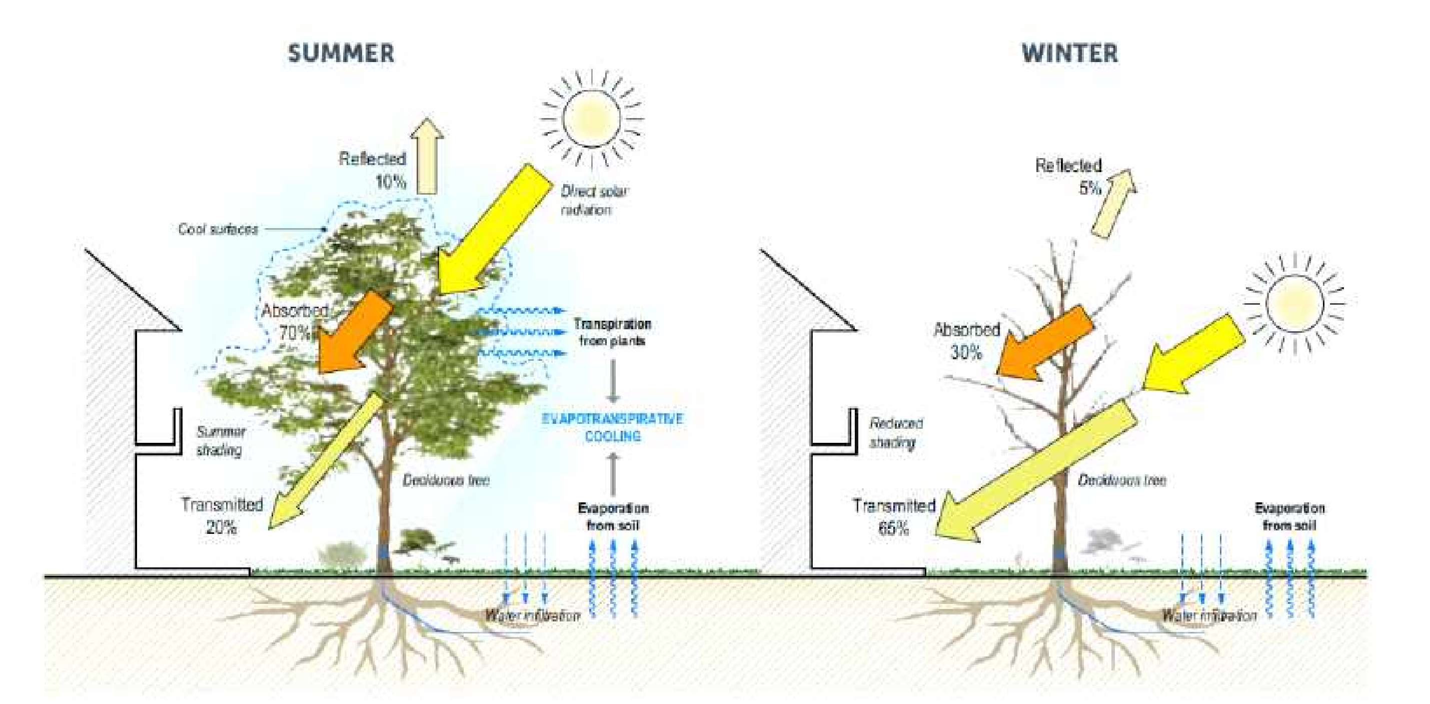



**Figure 12.** Cooling effect of a tree in a sunny day in summer and winter (Cooperative Research Centre for Low Carbon Living, 2017).

Conservation Act, and is characterised by the assemblage of plants set out at: [Environment.nsw.gov.au/topics/animals-and-plants/threatened-species/nsw-threatened-species-scientific-committee/determinations/final-determinations/2008-2010/cumberland-plain-woodland-critically-endangered-ecological-community-listing].

Selection of suitable species from this community will meet the objective of biodiversity conservation as well ` as cooling the built environment.

Other tree selection criteria applied here include functional diversity, i.e. possession of a variety of characteristics which lend themselves to different aspects of cooling (providing shade, channelling or blocking wind, capacity to cope with warming climate) and alignment with appropriate species from the existing Hills Shire street tree list.

The "Which Plant Where" online tool (Staas and Leishman, 2017) was applied to extract tree and shrub species which are suitable for the Norwest location and able to provide shade (or act as a windbreak in the case of shrubs), attract beneficial fauna such as birds and pollinators and tolerate a hotter climate as projected for 2070.

What is excluded is as important as what is included, and to that end we refer you to the environmental weed list provided by the Hawkesbury River County Council, which was set up in 1948 as a single-purpose Council for the control of Priority Weeds, and includes the Hills Shire and the Cities of Blacktown, Hawkesbury and Penrith.

Most of the serious weeds in Australia were originally introduced from overseas (often for aesthetic reasons) and subsequently escaped from private and public gardens. They cost the Australian economy more than $3 billion annually – and this excludes significant additional costs to human health and the environment. The weeds list can be accessed at: hrcc.nsw.gov.au/weed-information/priority-weeds-list.

### Natural turf and groundcover species

#### HOW IT WORKS AND HOW TO IMPLEMENT

Natural turfs and groundcovers use similar principles for surface cooling through evapotranspiration. However, unlike trees, they do not provide shade, so the cooling effect is highly dependent on maintaining irrigation and soil moisture.

The surface temperature of well-irrigated grassed areas can be up to 15°C cooler than surrounding paved areas when exposed to direct solar radiation. However, the cooling potential can reduce to less than 5°C for dry turfs.

Grasses can be integrated with (or replace) artificial materials in urban pavements and parking lots, reducing the surface temperature, improving thermal comfort for pedestrians, and helping to mitigate the urban heat island effect.

### Green roofs

Establishing green roofs involves adding a vegetation layer such as shrubs, grass, and/or small trees onto building rooftops. Green roof absorbs less solar radiation than a dark roof surface such as concrete or bitumen thanks to its higher albedo (see also the discussion of cool roofs and walls on pg. 29).

#### HOW IT WORKS

Green roofs comprise a modified roof system incorporating a drainage layer, root barrier and often an insulation layer, with different types of vegetation planted in a suitable growing medium (Figures 13. and 14. on pg. 25). Green roofs enable surface cooling and at the same time reduce the heat transfer to the 'host' building and thus lower the building cooling energy demand.

Air temperature adjacent to the roof is also influenced by evapotranspiration (and shade, if small trees are installed), which can make an accessible green roof an attractive venue for relaxation or recreation activities. Roof areas account for 40-50% of total impermeable areas of developed cities, so widespread installation of green (and cool) roofs could contribute to reducing urban overheating at neighbourhood or even city-wide scale.

Much evidence has accumulated that green roofs can play a significant role in stormwater management, supporting local biodiversity and enhancing urban ecosystems (Shafique et al., 2018).

The cooling performance of green roofs largely depends on factors such as height and density of canopy, climatic conditions (solar radiation, growth media moisture content, wind speed, precipitation) and construction parameters (depth of growing medium, roof load bearing capacity) (Jamei et al., 2021).

When green roofs were installed on buildings with a height of around 10m, air temperature reduction at pedestrian level was found to be around 0.6°C (Berardi, 2016; Ouldboukhitine et al., 2014). However, when used on medium to high-rise buildings, the cooling effect on the pedestrian level becomes negligible.

#### HOW TO IMPLEMENT

Green roofs are commonly classified into two categories, extensive and intensive, based on substrate thickness. Intensive green roofs are characterised by greater substrate depth, hence greater water holding capacity and ability to support a diverse range of plant heights and root depths. Intensive green roofs require more consideration of the building's structural capacity and usually require substantial maintenance.

Extensive green roofs are shallow and lightweight, so can be implemented within typical building roof loading restrictions (hence may not be accessible to building occupants) and are often used to cover larger roof areas. They require less maintenance compared with intensive roofs as well as lower capital costs.

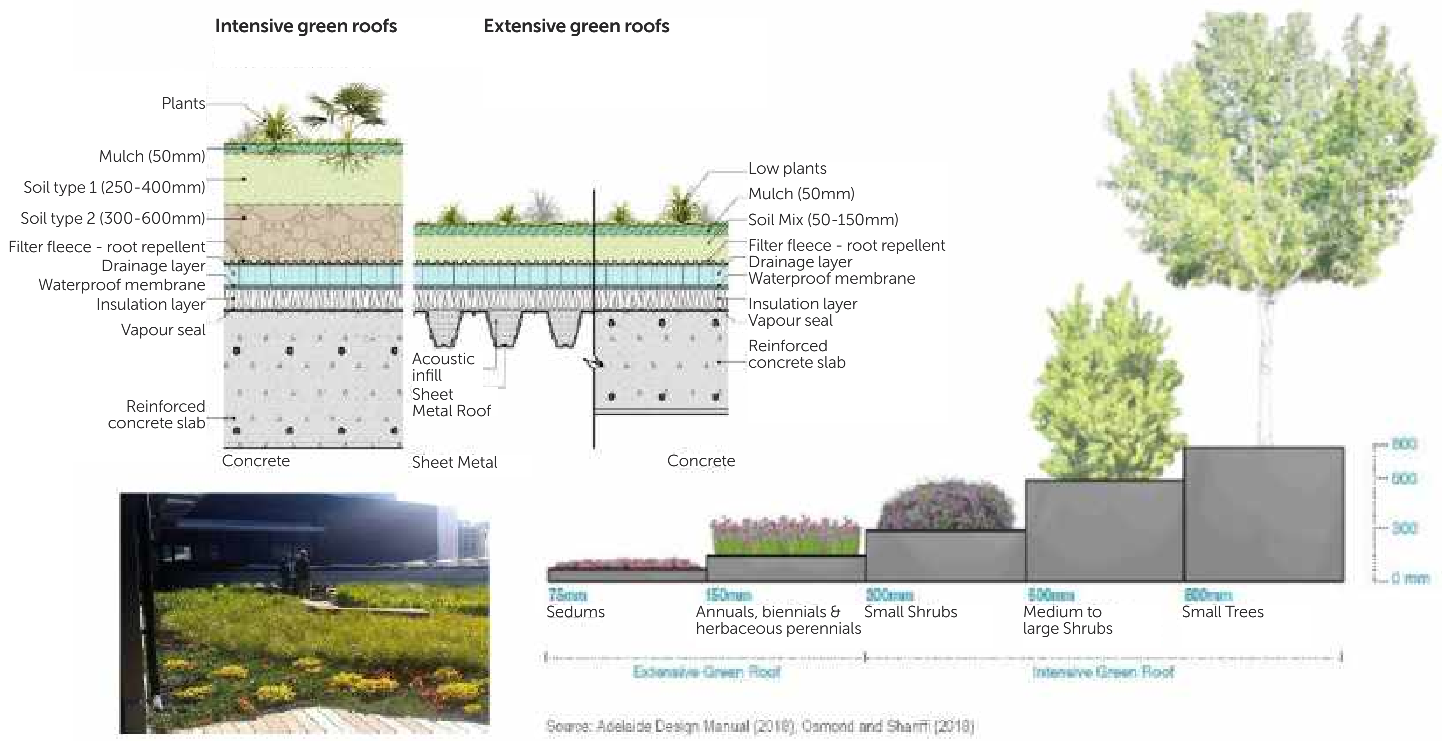



**Figure 13.** Types of green roofs, their characteristics and typical plant selection (DELWP, 2020).

**Figure 14.** Examples of green roof types being built in Australia (Williams et al., 2021): a) Burnley demonstration green roof, University of Melbourne (Julia Schiller); b) Victorian Comprehensive Cancer Centre, Melbourne (Julia Schiller); c) The Venny, Melbourne (John Rayner); d) Victorian desalination plant, Wonthaggi (Leanne Hanrahan); e) Yerrabingin Indigenous Rooftop Farm, Sydney, Junglefy; f) Anadara and Alexander Residences, Sydney; g) 38 Westbury Street (Julia Schiller); h) and i) private residences, Melbourne (Julia Schiller). Reprinted from Urban Forestry and Urban Greening, 62, Williams, N.S. et al. Ten years of greening a wide brown land: A synthesis of Australian green roof research and roadmap forward, pp 127-179. Copyright (2021) with permission from Elsevier.

Table 2. Selection guide for extensive and intensive green roofs (CRC for Low Carbon Living, 2017)

| ATTRIBUTE | EXTENSIVE ROOFS | INTENSIVE ROOFS |
|---|---|---|
| **Soil depth** | 50-150 mm | 150-400 mm |
| **Weight** | 75-250 kg/m$^2$ | More than 250 kg/m$^2$ |
| **Plants type** | Low growing plants 5-600mm | All heights |
| **Plants height** | Low growing plants 5-600mm | All heights |
| **Roof slope** | Up to 30° pitch | Relatively flat |
| **Usage** | Usually non-accessible and non-recreational | Designed for human recreation, gardening and social activities |
| **Cost** | \$50-250 / m$^2$ | \$250-400 / m$^2$ |
| **Water requirement** | Low irrigation required | Artificial irrigation usually necessary |
| **Maintenance** | Low maintenance | High maintenance |

Table 2. above outlines the recommendations and cost for the implementation of intensive and extensive roof types.

It is recommended to use plants that can tolerate heat, wind, droughts and full sun. Irrigation is important for roof plants to provide effective cooling benefits; introducing a rainwater collection system can meet this need and support the reuse of rainwater to reduce ongoing costs.

### Vertical greenery

Vertical greenery refers to vegetation which is grown on, up or against building facades and other vertical surfaces (Figure 15. on pg. 27).

#### HOW IT WORKS

Vertical greenery systems reduce building surface temperature by increasing thermal insulation of building envelopes (including through the air gap between the plants and the façade), intercepting solar radiation, and increasing evaporative cooling. Vertical greenery structures can be used as a passive energy-saving system, and when implemented at pedestrian height, can improve the human thermal comfort.

Vertical landscaping can reduce building envelope surface temperatures by up to 20°C (Mazzali et al., 2013). A 2°C mean annual air temperature reduction was reported for spaces immediately adjacent to green walls. Like the other green infrastructure, the cooling effect of vertical greenery is highly dependent on wall orientation, plant density and substrate water content.

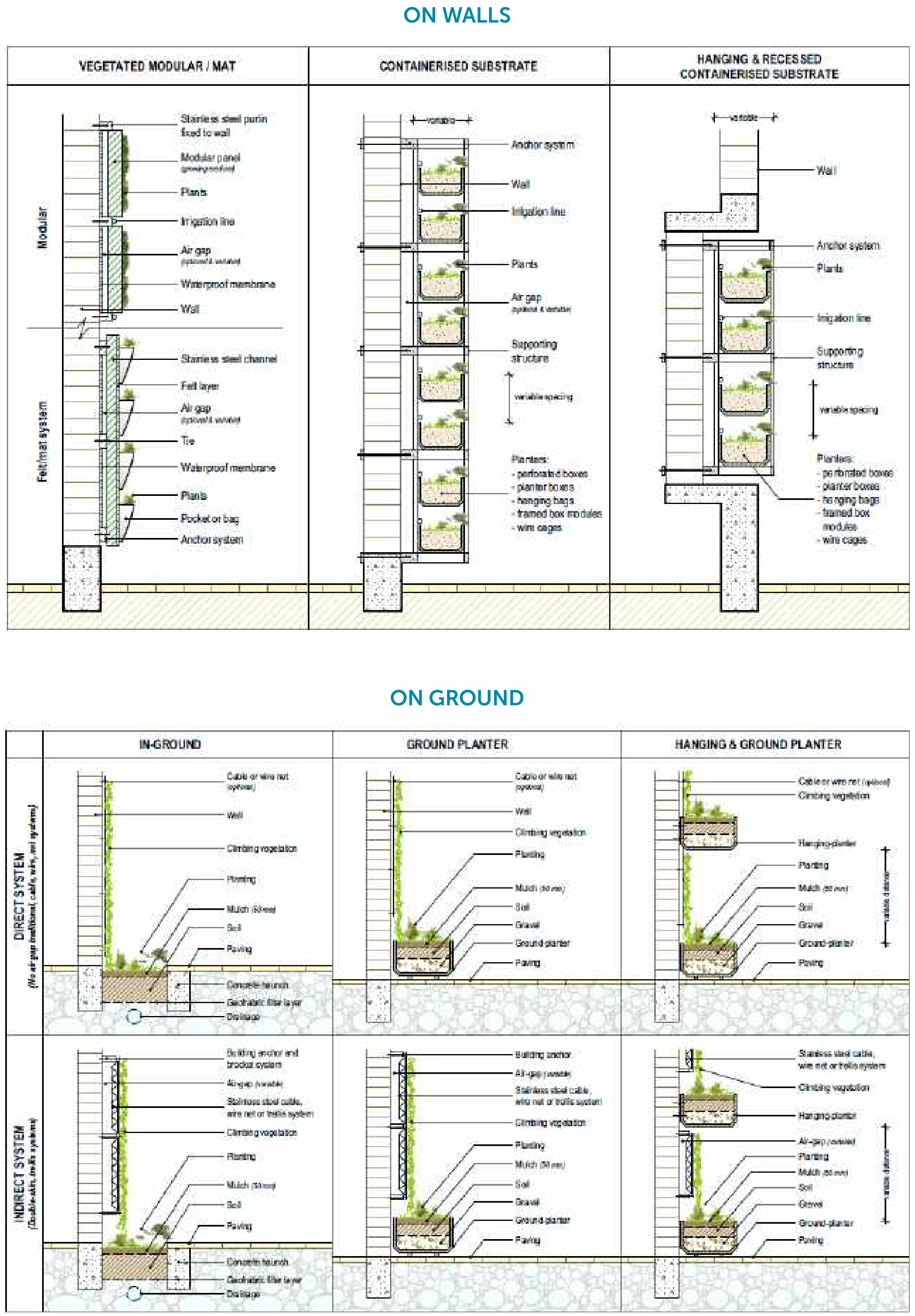



Figure 15. Vertical greenery typology (CRC for Low Carbon Living , 2017).

## HOW TO IMPLEMENT

Based on the type of support structures and vegetation, vertical greenery systems can be divided into two categories, green façades and living walls. In green façade systems, vegetation cover is usually formed by climbing plants, which are rooted at the base of the façade in the ground or in plant boxes, but intermediate planters, or green cascades falling from the rooftops can also be used.

Some light-weight structures such as guide wires can be used to guide the plants' development along the building wall. Using a stronger supportive structure, living wall systems allow a wider range of plant choice and use containers or pre-vegetated panels fixed to the façade.

An irrigation network is necessary for living wall systems, so a waterproof backing is required to isolate the living wall from the building in order to avoid problems associated with dampness (Pérez-Urrestarazu et al., 2015).

Green façade systems usually require less maintenance and protection, and are therefore suitable for low- and mid-rise buildings, whereas living wall systems can be also applied to mid- and high-rise buildings, but require more expensive construction and maintenance.

## COOL SURFACES (MATERIALS)

The excess absorption of solar gain by urban structures is the main source of urban heat island effects. To mitigate the unwanted heat, materials with high solar radiation reflectivity, low solar absorptivity, less heat capacity (stores less heat in its volume), low heat conductivity (conducts less heat into its interior), and/or high permeability (evaporative cooling) are applied to urban paving and building envelopes.

### Cool paving technologies

#### HOW IT WORKS

Paving accounts for 25-50% of urban surfaces. Traditional paving materials, such as asphalt and concrete are hard, impermeable, and with low solar reflectance their surface temperature can reach up to 70°C or more on a hot summer day. Compared to conventional pavements, reflective pavements absorb less solar radiation by increasing reflection particularly in the infrared and near IR wavelengths and thus have a lower surface temperature. Permeable pavements allow water to infiltrate into the soil below, which increases evaporative cooling and reduces surface and near-surface temperatures (Figure 16. below).

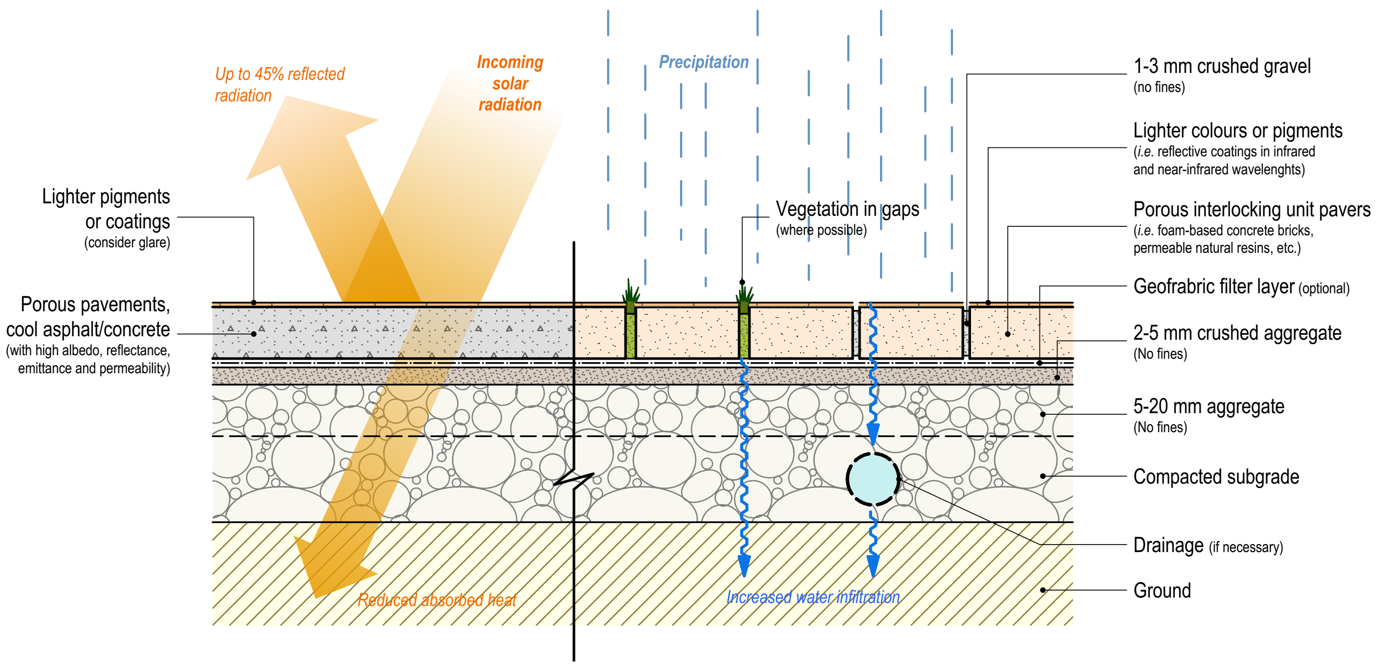



**Figure 16.** Cool and permeable pavements (CRC for Low Carbon Living, 2017).

#### HOW TO IMPLEMENT

Pavement can be retrofitted to become more reflective by applying broad spectrum reflective or (better) infrared reflective paints over the surface. A 'cool asphalt' compound can increase the reflectance of conventional asphalt from 20% or less to 45%.

Using alternative constituents (e.g., lighter pigment, aggregates, and slag) in asphalt, concrete, and other pavement materials is another common option, which can increase the surface reflectance up to 30%. Although reflective pavement has a lower surface temperature, the enhanced radiation reflection can increase pedestrian thermal exposure and cause glare effects to pedestrians and motorists.

Permeable pavements include both non-vegetated and vegetated examples. Non-vegetated permeable pavements include porous asphalt, pervious concrete, and block pavers; vegetated permeable pavements can be grass pavers or concrete grid pavers which allow vegetation to grow.

The application of different cool pavement options will largely depend on the street geometry and intended activities, traffic conditions, and maintenance availability.

Table 3. on pg. 30 summarises 11 common cool paving technologies.

### Cool building envelopes / cool roofs

#### HOW IT WORKS

Building rooftops cover almost 20% of the urban surfaces in Australian cities. Conventional roof surfaces can reach a surface temperature 50-90°C on a typical summer day due to a low solar reflectance (generally 5-25%) and lack of shade. With more than 80% of the incoming solar energy absorbed by roof surfaces, heat transfer into the building can cause significant stress to the indoor thermal comfort and building cooling systems.

Cool roofs are typically white or light coloured with high solar reflectance (to increase the fraction of solar energy that is reflected by and roof) and high thermal emittance (to increase the ability of roof surface to radiate absorbed heat) (Figure 17. below).

Cool roofs can reduce average surface temperature by about 10°C during the daytime in summer, and the reduction of peak surface temperature can reach 33-42°C.

The indoor air temperatures in the occupied space directly below the cool roof can be decreased between 1.2°C and 4.7°C, with average annual temperature reduction of 2.5°C.

Such temperature reductions can save 18% to 34% cooling energy consumption (and associated costs) during summer, although 10% more energy may be needed for winter heating in temperate climates.

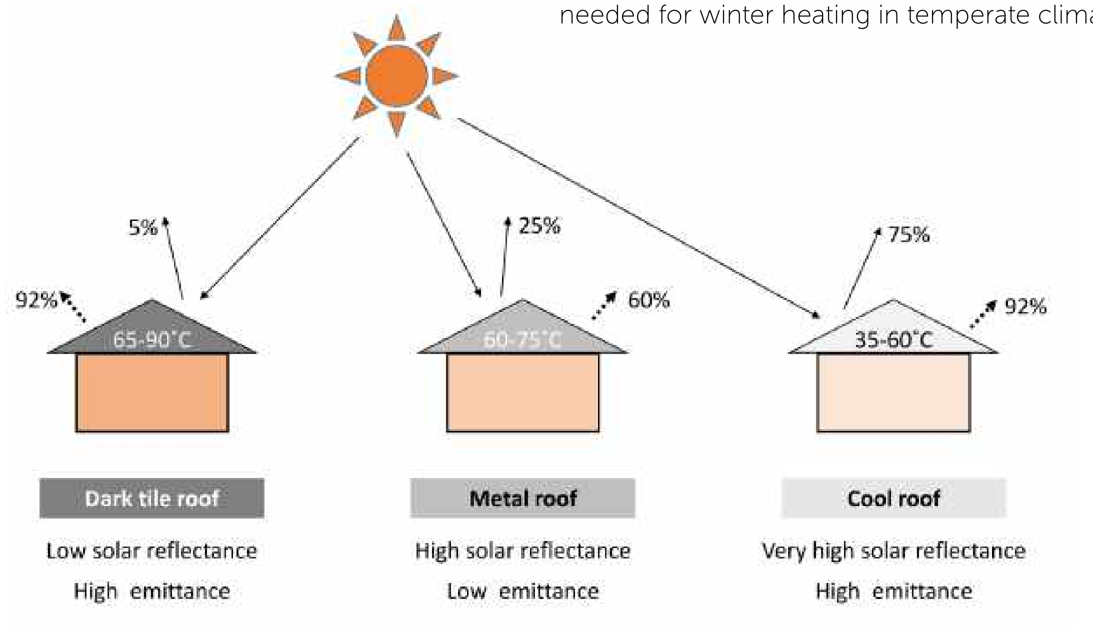



**Figure 17.** Cool and permeable pavements (CRC for Low Carbon Living, 2017).

**Table 3.** A summary of common cool paving technologies (CRC for Low Carbon Living, 2017).

| COOL SURFACE TYPE | TECHNOLOGY | URBAN CLIMATE IMPACT | ISSUES TO CONSIDER | TARGET USE |
|---|---|---|---|---|
| **High albedo asphalt** | Asphalt pavement modified with high albedo materials or treated after installation to raise albedo. | • Can increase solar reflectance up to 20% more than conventional asphalt.<br>• Lower surface temperature day and night. | • Solar reflectance of asphalt increases over time.<br>• Solar reflectance of concrete decreases over time.<br>• Reflected radiation may be absorbed by other surfaces.<br>• Low surface temperature does not directly result in low air temperature.<br>• Solar reflectance increase over time.<br>• Urban geometry needs to be carefully considered. | Paving large exposed areas such as roads and parking lots. |
| **Chip seal, micro surfacing and white topping** | Applying plastic-based aggregate to resurface asphalt. | | | |
| **High albedo concrete** | Portland cement mixed with water and light aggregate. | • Can increase solar reflectance to 40-70%<br>• Lower surface temperature day and night. | | |
| **Coloured asphalt** | Applying coloured pigments or seal when new or during maintenance. | • Can increase solar reflectance to 20-70%<br>• Lower surface temperature day and night. | Issues as above, and in addition:<br>• Traffic makes the pavement darker over time.<br>• Surfaces may wear away with polishing. | Low traffic areas such as sidewalks, driveways and parking lots. |
| **Coloured concrete** | Applying coloured binder or aggregate when new or during maintenance. | | | |
| **Resin-based concrete** | Using natural clear coloured tree resins in place of cement to bind the aggregate. | • Albedo is mainly determined by the colour of the aggregate.<br>• Lower surface temperature day and night. | | All applications including large exposed areas such as roads and parking lots and low traffic areas such as sidewalks and driveways. |
| **Permeable asphalt** | Using rubber or open-grade aggregate to provide more void spaces in asphalt to drain water. | When moisture is available in or bellow that surface, lower surface temperature through evaporative cooling day and night | • The cooling mechanism depends heavily on available moisture.<br>• When dry, daily surface temperature may be higher than conventional surfaces but this does not affect nocturnal surface temperature.<br>• Void spaces can become filled with dirt over time.<br>• Best to use in climates with adequate moisture during summer. | |
| **Permeable concrete** | Using foam or open-grade aggregate to provide more void spaces in concrete to drain water. | | | Low traffic areas such as sidewalks, driveways and parking lots. |
| **Block pavement** | Clay or concrete blocks filled with rocks, gravel or soil. | | | |
| **Vegetated pavement** | Clay, plastic or concrete blocks filled with soil and covered with grass or other vegetation. | | • The cooling mechanism depends heavily on available moisture.<br>• Sustainability of the vegetation may vary with local climate conditions and available moisture. | |

## HOW TO IMPLEMENT

Unlike cool pavement, solar glare at ground level is rarely an issue for commercial and high-rise residential buildings, but occupants of adjacent buildings may be affected.

Moreover, for residential buildings with steeply pitched roofs which can be seen from the ground, the effect of glare on pedestrian routes and public open space still needs to be considered when choosing roofing materials.

To address glare, more recently developed cool materials which reflect the invisible heat component of sunlight (longwave radiation in the infrared and near infrared) with less reflection in the visible wavelengths can be an option. The installation of cool roofs may increase heating energy requirements in winter, so annual heating and cooling loads should be considered together.

Other possible aspects to consider when installing/applying cool roofs include the life expectancy of cool materials, peak energy demand, building size, and sun blockage from trees and adjacent buildings.

Table 4. on pg. 32 sets out the key issues to consider when implementing cool roofs.

## DIRECT WATER-BASED EVAPORATIVE COOLING

Water-based evaporative cooling systems and surface water bodies are highly effective cooling strategies in drier climates such as north-western Sydney.

## HOW IT WORKS

The main cooling effect of water is to reduce the air temperature through evaporation. Meanwhile, the high thermal capacity of water (about four times higher than conventional construction materials) leads to lower surface temperatures compared with the surrounding ground and building surfaces during summer, and therefore less emission of longwave radiation.

Water bodies can act as heat sinks in urban spaces, increasing the convective heat transfer through the temperature difference between the water surface and surrounding air. Evaporative cooling can be categorised into passive and active systems.

**Surface / running water (passive)**

Passive evaporative cooling systems include lakes, ponds, cascades and fountains. The cooling effect of surface and running water largely depends on the size and distribution with respect to wind direction.

A greater cooling effect was found when ponds were oriented parallel to prevailing winds (Syafii et al., 2017).

Previous studies identified a reduction of 3-8°C in ambient air temperature with the presence of a nearby water body when the relative humidity was less than 50%. The most effective cooling from a 3.4 hectare lake was found to extend 10-20m from the lake edge (Xu et al., 2010).

**Evaporative spray cooling systems (active)**

Evaporative spray cooling systems provide thermal relief on hot days, even in a high humidity climate. Misting fans produce a cloud of very fine water droplets and cool the air through the evaporation of the water.

Studies have found that the cooling effect of a misting fan can be extended up to 5m from the fan, and within this range, 5-15°C air temperature reduction may occur depending on the weather conditions. For the pedestrians passing by, a misting fan can almost instantly decrease skin temperature.

Therefore, this active cooling system can be used to create cool spots for public spaces such as parks and plazas, particularly during heatwave events and where there is a significant proportion of hard surfaces.

Table 4. A summary of cool roof technologies (DELWP, 2020).

| COOL ROOF PRODUCT TYPE | COOL ROOF OPTIONS | SOLAR REFLECTANCE | UPFRONT COST ($)** | LIFE EXPECTANCY | TARGET USE (ROOF SLOPE) |
|---|---|---|---|---|---|
| **Coatings** | White | 0.7-0.85 | $-$$ | 5 to 20 years | Low or steep-sloped |
| | Aluminium | 0.2-0.65 | $$ | | |
| **Asphalt shingles** | White asphalt shingle | 0.2-0.3 | $$$ | 15 to 30 years | Steep-sloped |
| | Cool-coloured asphalt shingle (using a two-layer process) | 0.18-0.34 | $-$$ | | |
| **Tiles** | Terracotta ceramic tile | 0.25-0.4 | $-$$ | 50+ years | Steep-sloped |
| | White clay tile | 0.6-0.75 | | | |
| | White concrete tile | 0.6-0.75 | | 30 to 50 years | |
| | Grey concrete tile | 0.18-0.25 | | | |
| **Membranes** | White single-ply membrane (PVC or EPDM*) | 0.65-0.85 | $ | 10 to 20 years | Low-sloped |
| | Coloured membrane with pigments | 0.4-0.6 | $$ | | |
| **Metal Roof** | Unpainted corrugated (silver) | 0.2-0.6 | $-$$ | 20 to 50+ years | Low or steep-sloped |
| | White corrugated | 0.6-0.75 | | | |
| **Built-up Roof** | With white gravel | 0.3-0.5 | $-$$ | 10 to 30 years | Steep-sloped |
| | With white coating | 0.75-0.85 | | | |
| **Modified bitumen** | With mineral surface cap sheet | 0.1-0.2 | $$ | 10 to 30 years | Low-sloped |
| | White coating over mineral surface | 0.6-0.75 | $ | | |
| **Wood shake** | Bare light-coloured wood | 0.40-0.55 | $ | 15 to 30 years | Steep-sloped |

## SHADING

Shading blocks solar radiation, leading to direct reduction of surface and air temperature, therefore is a key measure to mitigate urban overheating and improve outdoor thermal comfort, especially in the middle of the day when the solar angles are highest.

Both permanent and temporary structures can provide shade. The former includes shade from buildings or other fixed structures, including integration of shading devices on building facades.

The latter includes devices which are installed only during the hottest time of year, or hottest time of day. Trees (discussed above) are of course living shading devices and can be permanent (evergreen) or temporary (deciduous trees which allow winter sun penetration).

### HOW IT WORKS

**Permanent shading structures**

Buildings can provide shade to nearby outdoor spaces such as footpaths, streets and squares and therefore improve pedestrian thermal comfort. A deeper street canyon also contributes to urban shading at street level, but at the same time can prevent radiant heat from escaping during the night.

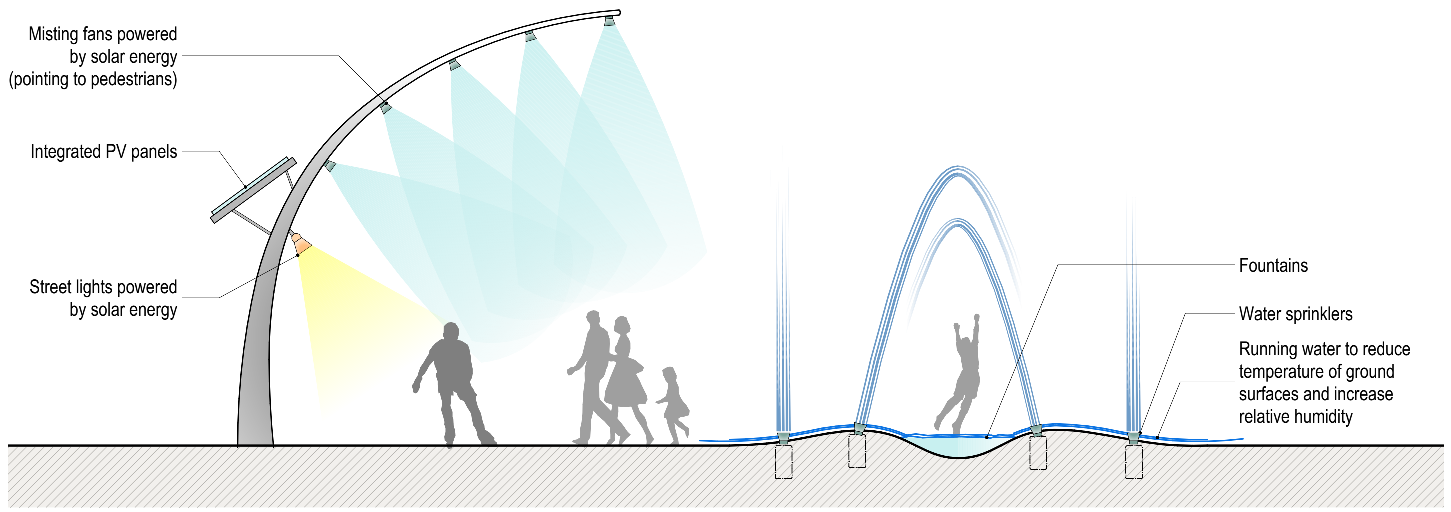



Figure 18. Example of different evaporative cooling systems (CRC for Low Carbon Living, 2017).

## HOW TO IMPLEMENT

**Table 5.** A summary of common evaporative cooling systems (DELWP, 2020).

| TYPE OF EVAPORATIVE COOLING | DESCRIPTION | TARGET USE | RECOMMENDATIONS |
|---|---|---|---|
| **Active evaporative cooling** | Corresponds to evaporative air-conditioners such as multi-stage evaporative coolers, fine water sprays, and misting fans (with or without induced air velocity. These are more effective in more humid regions [3, 4, 25]. | Recommended for public spaces with high pedestrian activity such as commercial development walkways, plazas, outdoor seating areas, carparks, etc. | A combination of active and passive evaporative cooling systems is highly effective.<br><br>Their installation in humid climates may result in increased relative humidity and decreased outdoor thermal comfort. [More information here [26] ]<br><br>They can be integrated with street furniture, pergolas, or shading structures to provide cooling effects to larger areas.<br><br>They should be preferably installed in the proximity of vegetation features (e.g. trees, grassed areas, shrubbery, etc.).<br><br>Integrated PV panels can collect energy that can be later used to cover the electricity demand necessary to operate these systems.<br><br>Harvested rainwater and stormwater from run-off can be reused to maintain evaporative cooling systems throughout the year. |
| **Passive evaporative cooling** | Includes the provision of tree plantings and water features (fountains, lakes, ponds, rivers, etc.), | Recommended for areas where extensive cooling benefits are required such as large open green spaces, squares, etc. | The intensity of cooling effects can be managed by modifying the depth and extent of water; so large and deeper water bodies can provide more cooling benefits compared to shallow water [11].<br><br>Streetscape irrigation and pavement watering (surface running water) during hot days or days prior to heatwaves can help on the provision of thermal cooling during extreme weather conditions<br><br>Harvested rainwater from buildings (from traditional buildings or living architecture solutions) and stormwater from run-off can be reused to maintain evaporative cooling systems throughout the year. |

## Ideally, buildings and other urban structures should be carefully spaced and oriented in a way which both shades and also facilitates heat dissipation and wind flow.

Optimised building orientation can lower solar exposure and therefore minimise solar gain. Shading devices such as canopies, brise-soleils and external blinds can be installed on or around building envelopes to further reduce the heat gains through facades.

At the same time, the designer of permanent shading structures should be aware of the effect on lighting and favourable solar access in winter.

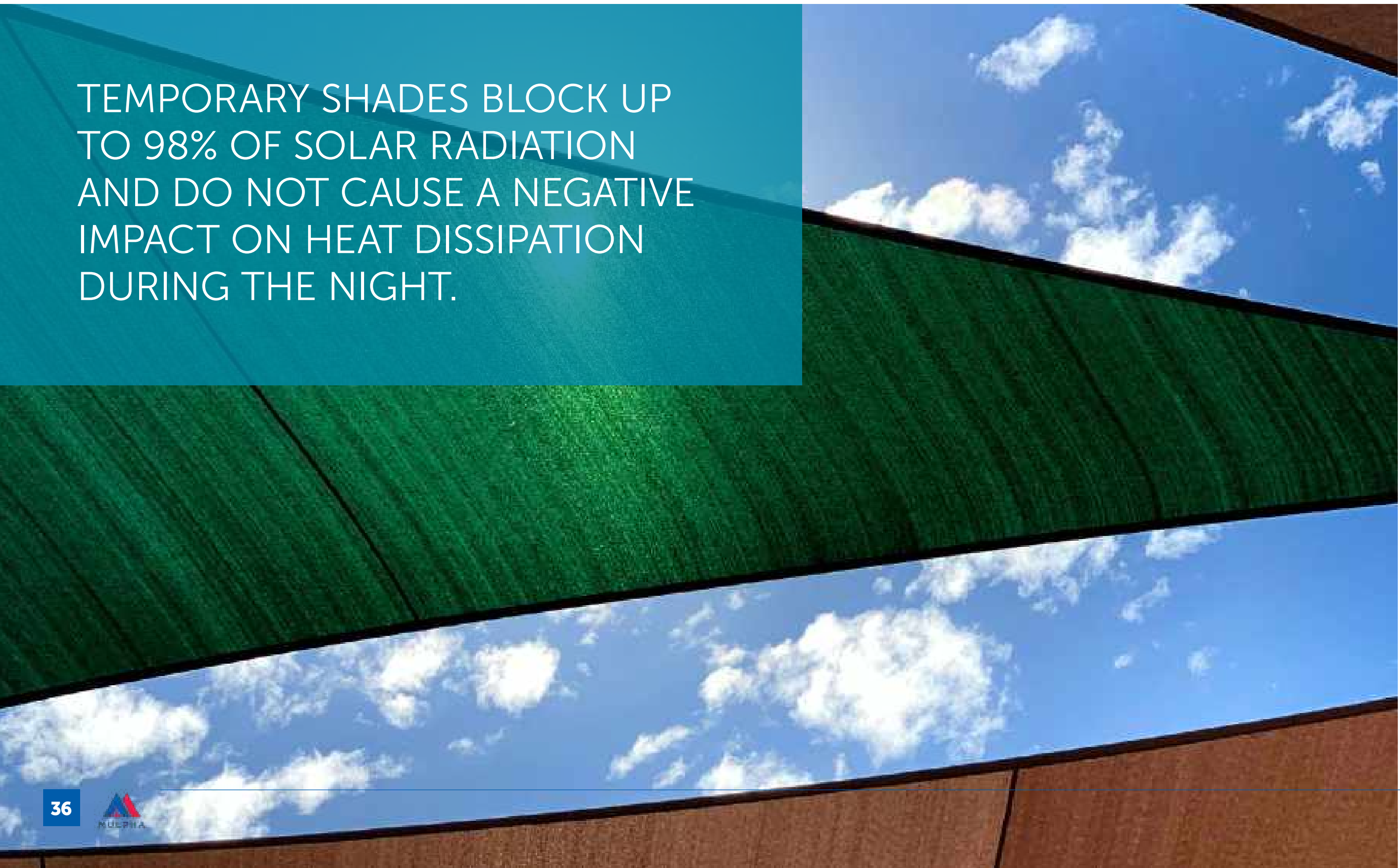
### Temporary shading structures

Temporary shades, such as awnings and market umbrellas can be removed when not needed. They therefore do not cause a negative impact on winter solar benefits and heat dissipation during the night, while still blocking up to 98% of solar radiation.

They can be adjusted to community needs, such as outdoor dining, public events, sports fields, and can be easily adapted to changing daily and seasonal sky conditions and solar angles.


**Figure 19.** Examples of permanent and non-permanent shading structures (DELWP, 2020).

Figure 20. Examples of permanent and non-permanent shading structures (CRC for Low Carbon Living, 2017) – note the solar photovoltaic panels.



TEMPORARY SHADES BLOCK UP TO 98% OF SOLAR RADIATION AND DO NOT CAUSE A NEGATIVE IMPACT ON HEAT DISSIPATION DURING THE NIGHT.

## HOW TO IMPLEMENT

**Table 6.** A summary of common evaporative cooling systems (DELWP, 2020).

| TYPE OF SHADING STRUCTURE | TARGET USE | UPFRONT COST ($) | COMMENTS |
|---|---|---|---|
| **Fixed building-integrated shading devices** | Overexposed walls, areas and open spaces near buildings where constant shading is required (i.e. north-facing areas). | $ | Sufficient width (at least 3.5m) and height (3.5-4.5m) should be prioritised and installed in overexposed areas. In relation to glazing, a useful rule of thumb for north-facing facades is that the outward projection of a shading device should be 46% of the height of the glazing.<br>Design solutions should be able to support traffic, loading areas and a variety of outdoor activities. |
| **Retractable building-integrated shading devices** | Overexposed walls, areas and open spaces near buildings where different levels of shading is required throughout the day and year. | $$ | Shading structure should preferably be light-coloured, high albedo and highly reflective materials, while also ensuring that the negative effects of glare on users are controlled.<br>Non-continuous awnings or with steps ups and breaks can facilitate air movement. |
| **Translucent awnings and pergolas** | Appropriate for areas with less solar exposure where natural light and energy production is pertinent or necessary (e.g. south- or east- facing footpaths). | $$-$$$ | Translucent PV-integrated systems can be combined with solid materials, fabrics, canvas and meshes. |
| **Contractible or mobile shades** | To be located in different areas based on occupational, daily and seasonal requirements.<br>Suitable for private and public open spaces with varied shading requirements. | $-$$ | Contractible or mobile shades are a customary practice in the dining and entertainment industry in Australia.<br>Shading structure should preferably be light-coloured, high albedo and highly reflective materials, while ensuring that the negative effects of glare on users are controlled. |
| **Permanent shading structures** | Overexposed areas (i.e. wide and north-facing footpaths, boulevards, pedestrian/shopping streets) and open spaces (i.e. plazas, squares, parks, playgrounds) where constant shading is required. | $$-$$$ | Shading structure should preferably be light-coloured, high albedo and highly reflective materials, ensuring that the negative effects of glare on users are controlled.<br>Shading structures can be used to harvest rainwater for irrigation and integrated with solar PV.<br>Evaporative cooling systems (e.g. ceiling fans, misting fans, or water sprinklers) could be integrated to shading structures to enhance outdoor thermal comfort. |

# FURTHER DESIGN RESPONSES TO HEATWAVES, HEALTH AND URBAN COOLING

## More intense and frequent heatwaves are already occurring in many parts of the world, including Australia.

Heatwaves typically have a noticeable start and end, last for a period of days and have an impact on human activities, health and wellbeing (McGregor et al., 2015). The Australian Bureau of Meteorology defines a heatwave as three or more days in a row when both daytime and night-time temperatures are unusually high.

More Australians have died from heatwaves in the past 100 years than from any other natural disaster (Coates et al., 2014). The elderly, infants and very young children, pregnant and lactating women, and those with pre-existing medical conditions, outdoor workers and the socially isolated are most at risk. The addition of the unusually high temperatures of a heatwave to the baseline effects of the urban heat island and climate change means that city areas can be even more lethal to their residents during a heatwave.

Previous sections have focused on mainstreaming cooling design into urban planning and design to contribute to long-term heat risk reduction.

Table 7. below lists some of the short-term measures that are especially efficient in heat wave conditions.

Attention should be first paid to sensitive land uses with vulnerable populations such as schools, healthcare and aged care facilities. Meanwhile, cooling the immediate outdoor spaces of a development such as to entry and exit points, forecourts and outdoor rest or lunch areas can directly benefit building occupants and visitors.

**Table 7.** A summary of common design responses to heatwaves (DELWP, 2020).

| GOAL | ACTION | INCREASED OR ADDITIONAL RESPONSE |
|---|---|---|
| **Day time cooling** | Enhance evaporative cooling. | • Install temperature activated mist sprayers.<br>• Increase use of open water (pools and fountains).<br>• Irrigate landscaped areas all summer.<br>• Use water sensitive urban design for stormwater management – irrigated with clean water or treated wastewater during dry periods. |
| **Reduce the day time heat accumulation** | Two key actions, of which shading is most important, to help ensure an area does not accumulate heat; (1) provide trees and artificial shade structures; and (2) use non-heat absorbing materials (high emissivity qualities). | • Increased shade reduces radiant temperature and may include installation of dynamic shade structures and extendable awnings.<br>• Specify surface materials with higher Solar Reflectance Index (SRI) closer toward a rating of 100 (considering minimisation of glare). |
| **Increase heat dispersal at night** | | • Orient buildings to capture prevailing evening breezes over summer.<br>• Ensure location of canopy trees allows for heat dispersal, i.e. not a continuous coverage.<br>• Avoid placing heat sources like the outdoor units (condensers/ compressors) of air conditioners under bedroom windows or near outdoor rest areas. |
| **Provide cool refuges** | While not specifically a design intervention, the provision of air conditioned public and semi-public indoor spaces, coupled with adequate information and communication, can save lives in a heatwave. | • Cool refuges can include air-conditioned shopping malls, and Council buildings such as libraries and schools etc.<br>• Councils and the media can play an important role in notifying residents when heatwave conditions are expected, and where to go to escape the heat.<br>• For commercial sites, providing a cool refuge on a summer's day may also increase visitor numbers. |

# SOME RULES OF THUMB

**Table 8.** Cooling capacities and main constrains of common cooling strategies (DELWP, 2020).

| INTER-VENTION | EFFECTS | NOTES |
|---|---|---|
| **Vegetation** | The surface temperature of well-irrigated grassed areas can be up to 15°C cooler than surrounding paved areas under full solar radiation in summer. However, such surface temperature reduction may become less than 5°C for dry turfs. | The key to successful cooling from vegetation is irrigation. |
| | Tree canopy cover can provide an average 15°C reduction in surface temperature in summer; a 10% increase in canopy cover can give up to a 1.2°C reduction in surface temperature. | Trees should be planted to the north of buildings and private/public open space for maximum shading. |
| | Shade from trees can reduce 'feels like' (i.e. physiologically equivalent) temperature by 7°C to 15°C. | |
| | Vertical landscaping can reduce building envelope surface temperatures between 5°C and 15°C. | The cooling effect of green walls is highly dependent on their orientation, plant density and irrigation regime. |
| | A mean annual air temperature reduction of 2°C is reported for outdoor spaces immediately adjacent to green walls. | |
| | Trees and shrubs can block hot winds and channel cooling breezes. | Accurate effects are complex and require modelling. |
| **Paving** | Concrete and other common paving materials have a solar reflectance of 25-40%. Their surface temperature can reach 65°C under full sun. | The effectiveness of cool paving is reduced over time by ageing and accumulation of dirt, currently a significant research topic. |
| | Evaporative cooling from permeable paving surfaces may decrease surface temperature by up to 20°C and ambient air temperature around the immediate location by 2°C. | |
| | Cool (high albedo/emissivity) paving may reduce ambient temperature around the immediate location by 2.5°C. | Evaporative cooling requires adequate water supply. |
| **Building envelope** | Conventional roof surfaces (with a solar reflectance of 5% to 25%) can reach a surface temperature of 50-90°C on a typical hot summer day. | Need to consider issues of reflectance and glare. |
| | A high-albedo (>0.65) / high emissivity (>85%) cool roof can radiate away up to 75% of incident solar energy. | |
| | Cool facades can reduce average indoor operative temperature up to 1.1°C during summer. | |
| | Cool facades can provide average exterior surface temperature reductions up to 7.5°C, with peak reductions up to 25°C. | |
| | Cool roofs can reduce surface temperature up to 33°C compared to conventional roofs and decrease indoor temperatures in the occupied space directly below the roof by 1.2–4.7°C (average annual temperature reduction of 2.5°C). | Can achieve cooling energy savings of 18%-34% during summer in a temperate climate. |
| **Water** | Temporary coverage of conventional (impermeable) paving with surface water can increase reflectance, utilise surface heat for evaporation and decrease the surface temperature by at least 5°C. | Technique practiced for centuries in Japan, now extending to some European cities. |
| | Evaporative cooling can lead to ambient temperature reduction of 3–8°C when relative humidity is less than 50%. | Evaporative cooling is highly dependent on air movement and humidity, and requires regular water supply. |
| | Misting fans affect distances up to 5m from the fan. Depending on weather conditions they can reduce air temperature by 5-15°C. | Effect is temporary (dependent on continued application of the fan). |

### URBAN COOLING CONTEXT-INTERVENTION MATRIX

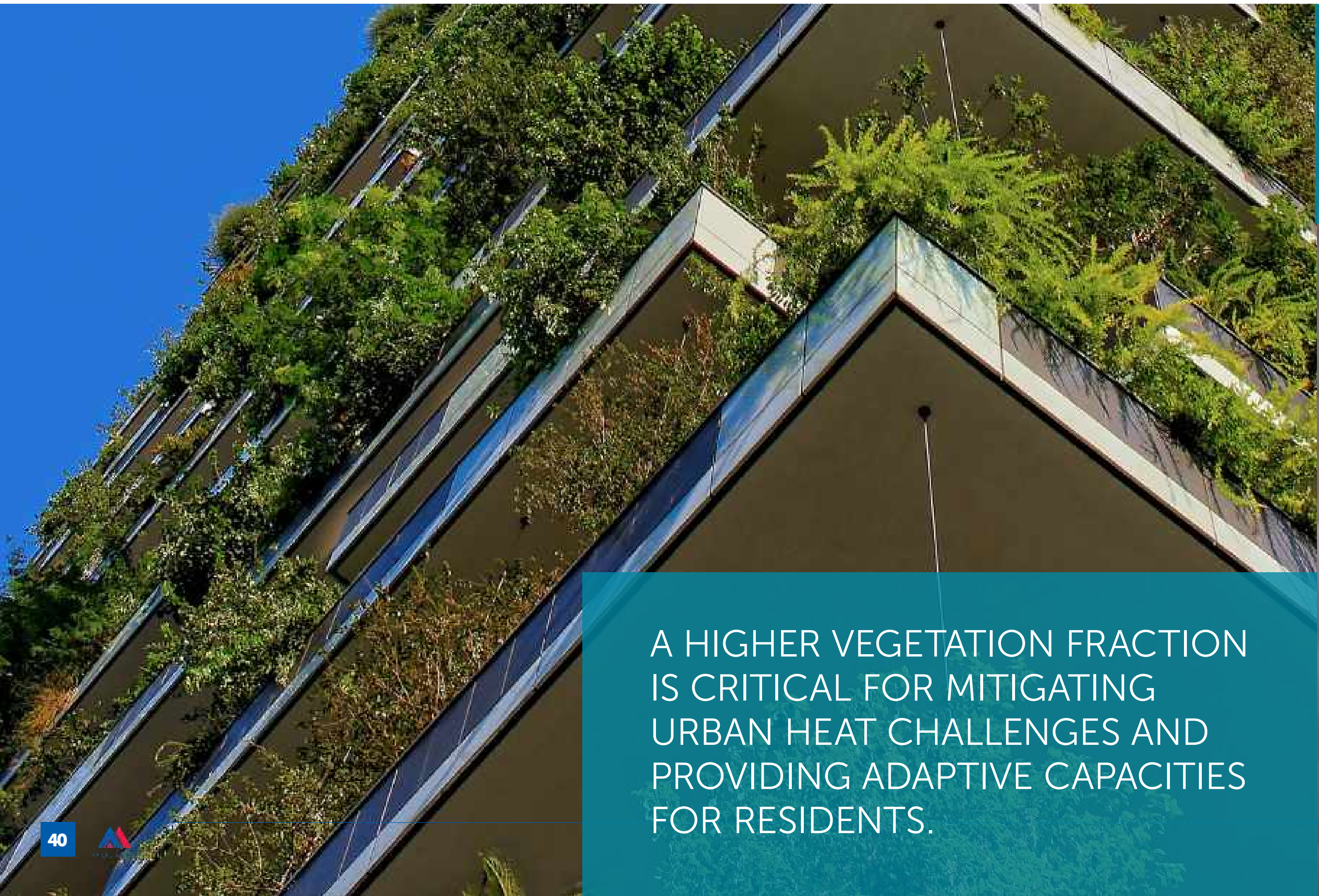
According to site inspections carried out by the UNSW team, compared to Sydney's more heavily urbanised east, the Norwest area has a higher vegetation fraction (10-40%), which is critical for mitigating urban heat challenges and providing adaptive capacities for residents.

The Norwest area also features a relatively lower urban density and average building height, with "compact low-rise", "open low-rise", "sparsely-built" and "large low-rise" local climate zone (LCZ) types (Stewart and Oke, 2012) accounting for more than 80% of the land cover.

Public spaces such as plazas, squares, and street are commonly surrounded by low-rise (less than six-storey) buildings, and therefore may not or only be partially protected from solar radiation due to the limited shade of surrounding buildings.

**Tree canopy and shading structures** are encouraged to be used to complete the shadow, and these public open spaces can benefit more from **evaporative cooling** from the tree canopy, permeable paving, and water features. Due to the low-to-medium SVF, using **high emittance cool paving** and **cool envelope** treatments facilitates less heat storage in public spaces such as plazas, street canyons and pedestrian open-air malls.

**High albedo surfaces** are normally not suggested for the public realm due to effects of potential glare and reflected solar radiation on pedestrians, but can generally be used on building rooftops. Due to the domination of steep roofs in inner and middle suburbs more opportunity is available to use **cool roofs** compared with green roofs (which prefer flat surfaces).




## DEVELOPMENT TYPOLOGIES AND BEST PRACTICE

Whenever possible, outdoor cooling strategies should be integrated into the decision-making process right from the start of the project and iterated with the design process, to avoid designing in problems.

**Before you start, set cooling targets for your specific development site.**

Table 9. on pg. 42 includes some case studies of applying suitable cooling strategies for different built form typologies. Types and characteristics are based on DELWP (2020), and typical images were collected from the Norwest area using Google Map.

## RESIDENTIAL DEVELOPMENT CASE STUDIES

### Development characteristics

**Table 9.** Residential development characteristics.

| DEVELOPMENT TYPE | AERIAL IMAGE | DEVELOPMENT CHARACTERISTICS |
|---|---|---|
| **Low density residential single lot** |  | • Individual single-storey detached houses occupying a large portion of the lot.<br>• Dark roof materials, asphalt-paved roads and concrete-paved footpaths and driveways.<br>• Small gardens with sparse or no tree canopy coverage with poorly irrigated grassed areas. |
| **Low density residential single lot** |  | • Single or double storey (split) houses (also traditional terrace/row housing) occupying a large portion of the lot.<br>• Limited private garden space.<br>• Limited amount of tree cover in streets and private outdoor spaces.<br>• Dark roof materials, asphalt-paved roads and concrete-paved footpaths and driveways. |
| **Medium density residential townhouse** |  | • Mid-rise multi-dwelling buildings or larger townhouses, occasionally with street-level shops/cafes (moderate pedestrian intensity) and residential units above (up to three storeys).<br>• Sparse tree canopy coverage and low to medium permeable surfaces in private and public areas.<br>• Dark roof materials, asphalt-paved roads and concrete-paved footpaths and driveways. |
| **Medium density residential small apartment** |  | • Mid-rise multi-dwelling residential buildings or small apartments occupying most of the lot.<br>• May include street-level shops and cafes and residential units above (up to four storeys).<br>• Few or no trees and grassed areas in private and communal open spaces.<br>• Asphalt-paved roads and concrete-paved footpaths and driveways.<br>• Lack of shading in communal areas. |
| **High density \|residential apartment** |  | • High to mid-rise multi-dwelling residential and mixed-use buildings occupying most of the lot.<br>• May include street-level retail with high pedestrian activity and residential units above (four storeys and more).<br>• Abundant paved surfaces (asphalt and concrete in roads footpaths and driveways).<br>• Few or no trees. Limited grassed areas in private and communal open spaces. |

### Most effective cooling design measures

The "most effective measures" under each section refer to the typology in that specific case study - for example, this particular set of cooling design measures refers to the "residential development" typology.

- A combination of **cool materials** and **large tree canopy**
- A combination of **cool materials** and **shading**
- **Large tree canopy**

**Table 10.** Suggested cooling strategies for residential construction types (DELWP, 2020).

| DEVELOPMENT | INDIVIDUAL STRATEGIES [a] | | | | | COMBINATION OF STRATEGIES [a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cool materials | Large trees | Small trees | Shading | Green roofs | Cool materials + Large trees | Cool materials + Small trees | Cool materials + Shading | Green roofs + Large trees | Green roofs + Vertical greenery | Green roofs + Vertical greenery + Small trees |
| **Low density** *(Greenfield single lot)* | 2 | 4 | 3 | 2 | - | 4 | - | 3 | - | - | - |
| **Low-medium density** *(dual lot split)* | 3 | 4 | 2 | 2 | - | 4 | - | 3 | - | - | - |
| **Medium density** *(Larger townhouse)* | 2 | 3 | 1 | - | 0 | 4 | - | - | 3 | - | - |
| **Medium density infill** *(small apartment)* | 2 | 3 | 2 | - | 0 | 4 | 3 | - | 3 | - | - |
| **High density** *(Apartment)* | 2 | 3 | 2 | - | - | 4 | - | - | - | 1 | 2 |

[a] **Effectiveness:** 4 = Very high; 3 = High; 2 = Medium; 1 = Low; 0 = Negligible; - Not simulated.

## COMMERCIAL DEVELOPMENT CASE STUDIES

### Development characteristics

**Table 11.** Commercial development characteristics.

| DEVELOPMENT TYPE | AERIAL IMAGE | DEVELOPMENT CHARACTERISTICS |
|---|---|---|
| **Local centre** |  | • Medium to large scale commercial buildings of single to multiple storeys that provide a range of retail, business, entertainment, and community functions that serve the day-to-day needs of residents.<br>• Predominantly metal sheeting or concrete roofs.<br>• Abundant asphalt-paved roads (usually carparks) and concrete-paved footpaths.<br>• Low or no tree canopy coverage and limited permeable surfaces in outdoor open areas. |
| **Commercial centre** |  | • Large to very large multi-storey commercial buildings that provide a range of retail, business, entertainment and community functions that serve the needs of the local and wider community.<br>• Predominantly metal sheeting or concrete roofs.<br>• Abundant asphalt-paved roads (usually carparks) and concrete-paved footpaths.<br>• Low or no tree canopy coverage and limited permeable surfaces in outdoor open areas. |

### Most effective cooling design measures

- A combination of **cool materials** with **large tree canopy, shading and evaporative cooling**
- **Shade structures**
- **Large tree canopy**

**Table 12.** Suggested cooling strategies for commercial construction types (DELWP, 2020).

| DEVELOPMENT | INDIVIDUAL STRATEGIES [a] | | | | | COMBINATION OF STRATEGIES [a] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cool materials | Large trees | Small trees | Shading | Green roofs | Cool materials + Large trees | Cool materials + Large trees + Evap. cooling | Cool materials + Large trees + shading | Green materials + Shading |
| **Local centre** | 2 | 3 | 3 | 0 | 2 | - | 4 | 4 | - |
| **Commercial centre** | 1 | 2 | 1 | 0 | 3 | 4 | - | - | 4 |

[a] **Effectiveness:** 4 = Very high; 3 = High; 2 = Medium; 1 = Low; 0 = Negligible; - Not simulated.

## INDUSTRIAL DEVELOPMENT CASE STUDIES

### Development characteristics

**Table 13.** Industrial development characteristics.

| DEVELOPMENT TYPE | AERIAL IMAGE | DEVELOPMENT CHARACTERISTICS |
|---|---|---|
| **Small industry** |  | • Open or compact arrangement of large low-rise buildings (1-3 storeys), warehouses or light industrial structures/factories.<br>• Predominantly metal sheeting or concrete materials in building envelopes.<br>• Extensive asphalt-paved loading zones and carparks, and abundant concrete paved surfaces.<br>• Few or no trees. Lack of grassed and shaded areas. |
| **Medium industry** |  | • Highly compact arrangement of large mid-rise buildings, warehouses or industrial structures/factories.<br>• Predominantly metal sheeting or concrete materials in building envelopes.<br>• Asphalt-paved loading zones and carparks, and abundant concrete-paved surfaces.<br>• Few or no trees. Lack of grassed and shaded areas. |
| **Large industry** |  | • Very large low and mid-rise buildings, warehouses or industrial structures/ factories that need to be separated from other land uses.<br>• Predominantly metal sheeting or concrete materials in building envelopes.<br>• Extensive asphalt-paved loading zones and carparks, and abundant concrete paved surfaces.<br>• Few or no trees. Lack of grassed and shaded areas. |

#### Most effective cooling design measures

- A combination of **cool materials** with **large tree canopy, shading and evaporative cooling**
- **Shade structures**
- **Large tree canopy**

**Table 14.** Suggested cooling strategies for industrial construction types (DELWP, 2020).

| DEVELOPMENT | INDIVIDUAL STRATEGIES [a] | | | COMBINATION OF STRATEGIES [a] | | |
|---|---|---|---|---|---|---|
| | Cool materials | Large trees | Shading | Cool materials + Large trees | Green materials + Shading | Cool materials + Large trees + shading |
| Small industry | 2 | 2 | 3 | 3 | 4 | 4 |
| Medium industry | 2 | 3 | 3 | 0 | 4 | - |
| Large industry | 2 | 2 | 3 | 4 | 3 | - |

[a] **Effectiveness:** 4 = Very high; 3 = High; 2 = Medium; 1 = Low; 0 = Negligible; - Not simulated.

## OPEN SPACES DEVELOPMENT CASE STUDIES

#### Development characteristics

**Table 15.** Open space development characteristics

| DEVELOPMENT TYPE | AERIAL IMAGE | DEVELOPMENT CHARACTERISTICS |
|---|---|---|
| **Parks and plazas** |  | • Parks are part of the urban infrastructure: for physical activity, for gathering and socialising, or for a simple respite.<br>• Parks may consist of trees, grassy areas, and water bodies.<br>• Many urban parks also offer benches for sitting, picnic tables and barbecue grills, fields for playing sports and games, trails for walking, biking and other activities.<br>• Plazas, on the other hand, may be predominantly paved. |
| **Streets and pathways** |  | • Streets perform basic functions in the built environment, providing connectivity, routes for movement of private motor vehicles, public transport, cyclists and pedestrians, and accommodating utility services.<br>• They usually comprise separate carriageways (defined by Transport for NSW as the "width of roadway for the movement of vehicles") and footpaths (for pedestrian movement and activities such as outdoor dining). |

#### Most effective cooling design measures

- A combination of **cool materials, with shading and evaporative cooling**
- **Shade structures**
- **Large tree canopy**
- **Direct water-based evaporative cooling**

With a general understanding of your development typologies, you can choose the cooling tools based on the advice provided in the 'Development Typologies and Best Practice' section from pgs. 41-47 to build the cooling plans for your development.

The most effective cooling design measures are always the combination of several cooling strategies.

Of course, urban cooling is not the only factor impacting master planning. There are a multitude of issues that must be taken into account, but understanding how the microclimate is impacted by the development goes a long way to support the city's liveability.

# SUPPORTING INFORMATION

## COOLING CHECKLIST/MATRIX

The intent of this matrix is to give an indication of the amount of cooling - both spot cooling and also affecting a wider zone of influence - of a range of interventions discussed in this Design Guide.

Note that these figures are only indicative, and dependent on a range of variables including seasonal and daily weather patterns, The information is adapted from the CRC for Low Carbon Living Guide to Urban Cooling Strategies.

**Table 16.** Cooling effects of mitigation interventions

| | MAX EFFECT ON SURFACE TEMPERATURE AROUND THE SPOT OF APPLICATION | MAX EFFECT ON AIR TEMPERATURE AROUND THE SPOT OF APPLICATION | MAX EFFECT OF PRECINCT SCALE AIR TEMPERATURE | MAIN CONSTRAINT |
|---|---|---|---|---|
| **Cool paving** | 33.0°C | 2.5°C | 2.0°C | Changes in reflectance over time (aging, dirt accumulation) |
| **Permeable paving** | 20°C | 2.0°C | | • Water supply<br>• Less efficiency in humid climates |
| **Cool envelope treatments** | 33°C | 2.5°C (indoors) | | Complex reflectance in street canyons |
| **Green envelope** | 20°C | 4.0°C | | • Water supply<br>• Horticultural maintenance |
| **Street trees** | 15°C | 4.0°C | | |
| **Parks** | 15°C | 4.0°C | | |
| **Evaporative cooling** | N/A | 8.0°C | | Water supply |
| **Misting fan** | N/A | 15°C | N/A | Effect is temporary |
| **Shading** | 15°C | N/A | N/A | |

- Passive and active cooling strategies and their key potentials and constraints.
- The UHI mitigation methods can be categorized into three major approaches: cool materials, increased greenery and energy efficiency.
- Water supply is the main constraint for cooling effect of urban greenery. The peak demand for water is similar to that of electricity during heatwaves.

**Table 17.** Optimal cooling interventions for different urban form typologies. For Norwest, the "other suburbs" category is generally most relevant, except for particularly built-up locations.

| URBAN CONTEXT | | SVF | COOL PAVING | | | COOL ENVELOPE | | GREEN ENVELOPE | | TREE CANOPY | EVAPORATIVE COOLING | | SHADING STRUCTURES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | HIGH ALBEDO PAVING | HIGH EMITTANCE PAVING | PERMEABLE PAVING | HIGH ALBEDO ENVELOPE TREATMENTS | HIGH EMITTANCE ENVELOPE TREATMENTS | GREEN ROOF | GREEN WALL | | SURFACE WATER AND EVAPORATIVE COOLING | MISTING FAN | |
| INNER CITY | Plaza | Low | N | 3 | 3 | R-3 | WR-3 | 3 | 3 | 1 | D-3 | HD-3 | 2 |
| | Square | Medium | 2 | 3 | 3 | R-3 | WR-3 | 3 | 3 | 3 | D-3 | HD-3 | 3 |
| | Street | Low | N | 3 | 3 | R-3 | WR-3 | - | 3 | 3 | - | - | 2 |
| | Pedestrian mall | Low | N | 3 | 3 | R-3 | WR-3 | 3 | 3 | 2 | D-3 | HD-3 | 3 |
| INNER SUBURBS | Plaza | Low | N | 3 | 3 | R-3 | WR-3 | 3 | 3 | 1 | D-3 | HD-3 | 3 |
| | Square | Medium | 2 | 3 | 3 | R-3 | WR-3 | 2 | 2 | 3 | D-3 | HD-3 | - |
| | Street | Medium | N | 3 | 3 | R-3 | WR-3 | - | 2 | 3 | - | - | - |
| | Pedestrian mall | Medium | N | 3 | 3 | R-3 | WR-3 | 2 | 2 | 2 | D-3 | HD-3 | 3 |
| OTHER SUBURBS | Plaza | Medium | N | 3 | 3 | R-3 | WR-3 | 3 | 2 | 1 | D-3 | HD-3 | 3 |
| | Square | High | 2 | 3 | 3 | R-3 | WR-3 | 1 | 1 | 3 | D-3 | HD-3 | - |
| | Street | High | N | 3 | 3 | R-3 | WR-3 | - | 1 | 3 | - | - | - |
| | Pedestrian mall | High | N | 3 | 3 | R-3 | WR-3 | 1 | 1 | 2 | D-3 | HD-3 | 3 |

D = Dry climate W = Wall Effectiveness
H = Humid climate R = Roof High = 3 Medium = 2 Low= 1 N = negative

## SUGGESTED SPECIES LIST

As noted in the 'Urban Green Infrastructure' section on pg. 21, trees help cool the urban environment by providing shade, through evapotranspiration, and by channelling cooling breezes and blocking hot winds.

The list set out on Table 18. on pgs. 50-53 combines examples from the local (and critically endangered) Cumberland Plain plant community, the Hills Shire street tree list and a number of other locally suitable species identified through the "Which Plant Where" software program, with the emphasis on characteristics such as shade, robust evapotranspiration and/or ability to act as windbreak.

Co-benefits such as biodiversity conservation and aesthetic preferences were also considered.

**Table 18.** Suggested species for Norwest to support urban cooling and co-benefits.

| Botanic name | Common name | Sources | Description | Boiodiversity* | Suitable for projected 2070 climate | Suitable under powerlines |
|---|---|---|---|---|---|---|
| *Acacia decurrens* | Black Wattle | Cumberland Plain list; Which Plant Where list | Evergreen native shrub/small tree 3-15 metres, yellow flowers. Highly drought tolerant, fast growing. Good windbreak species. | Partial | Y | Y |
| *Acacia implexa* | Hickory Wattle | Cumberland Plain list; Which Plant Where list | Evergreen native shrub/small tree 5-15 metres, cream to yellow flowers. Spreading canopy. Highly drought tolerant, fast growing. | Y | Y | Y |
| *Acacia parramattensis* | Parramatta Wattle | Cumberland Plain list; Which Plant Where list | Evergreen native shrub/small tree 2-16 metres, cream to yellow flowers. Upright canopy. Highly drought tolerant, fast growing. Good windbreak species | Y | Y | Y |
| *Angophora floribunda* | Rough Barked Apple | Cumberland Plain list; Which Plant Where list | 10-20 metre native evergreen tree, cream/white flowers. Rounded, spreading, upright canopy. High drought tolerance, medium growth rate. | Y | Marginal for 2070 | N |
| *Angophora subvelutina* | Broad-leaved Apple | Cumberland Plain list; Which Plant Where list | 10-20 metre native evergreen tree, cream/white flowers. Good park feature tree. Highly drought tolerant. | Y | Y | N |
| *Backhousia citriodora* | Lemon Scented Myrtle | Hills Shire street tree list; Which Plant Where list | Evergreen, small domed native tree to 18 metres. Forms an upright shrub which matures into a squat trunked tree with a rounded crown. The lemon scented leaves are dark green and the creamy-white flowers have a honey aroma. Moderate drought tolerance, variable growth rate. | Y | Y | N |
| *Bursaria spinosa* | Blackthorn | Cumberland Plain list; Which Plant Where list | Native evergreen shrub, 1.5-4 metres. Rounded, spreading canopy. Very spiky, provides refuge for small birds. Highly drought tolerant, fast growth. Good windbreak species. | Y | Marginal for 2070 | Y |
| *Callistemon citrinus_* | Bottlebrush 'Kings Park Special' | Hills Shire street tree list; Which Plant Where list | Evergreen native shrub growing to 4 metres. This hardy plant forms an upright shrub with abundant, red, bird attracting flowers. Moderate drought tolerance. | Y | Insufficient data | Y |
| *Corymbia citriodora* | Lemon Scented Gum | Which Plant Where list | Native evergreen tree, 10-35 metres. Spreading upright canopy, cream/white flowers, fast growth rate. Strong lemon fragrance from leaves. Drought tolerant. | Y | Y | N |
| *Corymbia henryi* | Coarse Spotted Gum | Which Plant Where list | Native evergreen tree, 15-20 metres. White flowers over Winter, Spring and Summer. High drought tolerance and fast growth rate | Y | Y | N |
| *Corymbia maculata* | Spotted Gum | Cumberland Plain list; Which Plant Where list | Native evergreen tree, 15-30 metres. Canopy is rounded, spreading and upright. Cream to white flowers. Highly drought tolerant, fast growth rate. | Y | Y | N |
| *Daviesia ulicifolia* | Gorse Bitter Pea | Cumberland Plain list; Which Plant Where list | Small native evergreen shrub, 1-2 metres with orange flowers in Winter and Spring. Spiky: good habitat for small birds / mammals / reptiles. High drought tolerance, fast growing. Low screen or windbreak species. | Y | Y | Y |
| *Dodonaea viscosa subsp. cuneata* | Wedge Leaved Hop Bush | Cumberland Plain list; Which Plant Where list | Small native evergreen shrub, 1-3 metres, with inconspicuous red flowers. Drought tolerant and fast growing. Useful as screen/ low windbreak. | Y | Insufficient data | Y |
| *Elaeocarpus angustifolius* | Blue Quandong | Which Plant Where list | 8-20 metre evergreen tree with cream to white flowers. Park feature planting. Moderate drought tolerance, medium to fast growth rate. | Y | Y | N |
| *Elaeocarpus reticulatus* | Blueberry Ash | Hills Shire street tree list; Which Plant Where list | Native evergreen, narrow domed tree from 3-12 metres. Erect habit with a dense crown. The leaves are pink-bronze maturing to green. The bell-shaped flowers are pink to white throughout summer. Moderate drought tolerance, medium to fast growing. | Y | Y | N |
| *Eucalyptus microcorys* | Tallowood | Which Plant Where list | 20-25 metre native evergreen tree, upright canopy shape. High drought tolerance, medium growth rate. Suitable as windbreak. | Y | Y | N |
| *Eucalyptus saligna* | Sydney Blue Gum | Which Plant Where list | 20-30 metre native evergreen tree, upright canopy. Moderately drought resistant and medium growth rate. | Y | Y | N |
| *Eucalyptus sideroxylon* | Mugga Ironbark | Hills Shire street tree list; Which Plant Where list | Evergreen native from 20-25 metres. Straight trunk with deeply furrowed bark and weeping branches. Leaves are slender and grey green, creamy-white to red-pink flowers in Autumn, Winter and Spring. Drought tolerant and variable growth rate. | Y | Marginal for 2070 | N |
| *Ficus rubiginosa* | Port Jackson Fig | Which Plant Where list | 6-40 metre native evergreen tree with a rounded, spreading canopy. Flowers are inconspicuous. Moderate drought resistance and medium to fast growth rate. | Y | Y | N |
| *Hymenosporum flavum* | Native Frangipani | Hills Shire street tree list; Which Plant Where list | Native evergreen tree, 6-10 metres. This tree has large, glossy green leaves and fragrant cream-yellow flowers in Spring and Summer. Park and garden feature tree. Moderate drought resistance and variable growth rate. | Y | Y | N |

| Botanic name | Common name | Sources | Description | Boiodiversity* | Suitable for projected 2070 climate | Suitable under powerlines |
|---|---|---|---|---|---|---|
| *Indigofera australis* | Native Indigo | Cumberland Plain list; Which Plant Where list | Native evergreen shrub, 1-3 metres, pink, purple and red flowers in Winter, Spring and Summer. High drought tolerance, medium growth rate. | Y | Marginal for 2070 | Y |
| *Jacaranda mimosifolia* | Jacaranda | Hills Shire street tree list; Which Plant Where list | Deciduous, broad domed exotic tree from 8-15 metres. This tree has a spreading open canopy with grey brown bark and masses of purple/ blue flowers in late spring on a leafless tree. The light green leaves are fern-like. Moderate drought tolerance, medium to fast grower. | Partial | Y | N |
| *Lagerstroemia indica* | Crepe Myrtle | Hills Shire street tree list; Which Plant Where list | Deciduous, vase shaped exotic tree to 6-8 metres. This tree has dark green leaves and mottled bark. The flowers are pink, blooming during summer. Moderate drought tolerance, medium to fast growth. Good park/garden feature tree. | Y | Y | Y |
| *Leptospermum petersonii* | Lemon Scented Tea Tree | Hills Shire street tree list; Which Plant Where list | Evergreen, narrow-domed native tree from 2-4 metres. This hardy tree has a slender weeping habit with glossy green leaves that have a lemon scent when crushed. The petite flowers are white blooming through summer. Highly drought tolerant, medium to fast growth rate. Good windbreak species. | Y | Y | Y |
| *Lophostemon confertus* | Brush Box | Hills Shire street tree list; Which Plant Where list | Evergreen, broad domed tree to 20 metres. Upright growth with a main trunk and spreading branches. The leaves are dark green, the flowers are cream and the bark is rough at the base with smooth pink branches. Good windbreak species, medium to fast growth rate. | Y | Y | Y |
| *Magnolia grandiflora* | Little Gem Magnolia | Hills Shire street tree list; Which Plant Where list | Evergreen, compact small-medium exotic tree from 4-6 metres. This tree has glossy green leaves and forms creamy-white saucer shaped flowers from an early age. Park/ garden planting. Moderate drought tolerance, slow growth rate. | Y | Y | Y |

| Botanic name | Common name | Sources | Description | Boiodiversity* | Suitable for projected 2070 climate | Suitable under powerlines |
|---|---|---|---|---|---|---|
| *Melaleuca linariifolia* | Narrow Leaf Paperbark | Hills Shire street tree list; Which Plant Where list | Fast growing, evergreen tree from 6-10 metres. Dense spreading crown with papery bark. The leaves are dark green with distinct light green new foliage. Masses of cream-white flowers in Spring and Summer. High drought tolerance, variable growth rate. Useful windbreak species. | Y | Y | N |
| *Pistacia chinensis* | Chinese Pistachio | Hills Shire street tree list; Which Plant Where list | Deciduous, broad domed exotic tree from 10-18 metres. This tree has a dark coloured trunk with well-spaced branches forming a rounded canopy. The mid- green leaves turn orange and red in Autumn and flowers are white. Moderate drought resistance, variable growth rate. | Partial | Y | N |
| *Prunus cerasifera 'Nigra'* | Cherry Plum | Hills Shire street tree list; Which Plant Where list | Exotic, deciduous, vase shaped tree from 4-6 metres. This tree has a short dark trunk, dark purple leaves and pale pink flowers. High drought tolerance, medium to fast growth rate. Feature and windbreak species. | Partial | Insufficient data | Y |
| *Pyrus calleryana* | Callery Pear | Hills Shire street tree list; Which Plant Where list | Deciduous, exotic, broad domed tree from 10-15 metres. This tree has a rounded canopy, glossy green leaves turning red in autumn. The flowers are white and have a strong perfume during spring. Moderate drought tolerance and medium growth rate. Park/garden feature species. | Partial | Y | N |
| *Quercus palustris* | Pin Oak | Hills Shire street tree list; Which Plant Where list | Deciduous, conical shaped exotic tree, growing to 15 metres. Shiny, deeply lobed, dark-green leaves, turning bronze in Autumn. Moderately drought resistant, slow to medium growth rate. | N | Y | N |
| *Tristaniopsis laurina* | Water Gum | Hills Shire street tree list; Which Plant Where list | Evergreen native tree growing from 5-15 metres. This tree's trunk has scaly bark when mature and spreading branches forming a dense crown. The leaves are glossy-green and the flowers cream to yellow. Moderate drought tolerance, medium to fast growth. Useful windbreak species. | Y | Y | N |

***Biodiversity**: Attracts a range of birds, insects, mammals, lizards, pollinators.

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