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Ark Resources

Green Infrastructure & The Urban Heat Island Effect for Nature Based Cities

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1.0 Introduction

Urbanisation has brought about unprecedented changes to the global landscape, transforming natural environments into sprawling urban centres. Today, more than 50% of the world's population lives in cities and forecasts suggest that this number will rise to 70% by 2050. Rapid urbanisation has transformed the landscape of cities, bringing forth numerous benefits in terms of economic growth, technological advancements, and improved quality of life. However, this urban sprawl has also given rise to a concerning phenomenon known as the Urban Heat Island (UHI) effect. Nature-Based Cities, recognising the pressing need to address this issue and increase green infrastructure in urban centres, has commissioned this research report to delve into the complexities of UHI and investigate the pivotal role that trees and vegetation play in mitigating its impacts.

The Urban Heat Island effect results from the alteration of land surfaces due to urbanisation, leading to increased heat absorption and retention. As impervious surfaces replace natural landscapes, cities become heat reservoirs, impacting local climates and ecosystems.

The significance of addressing the UHI effect extends beyond mere thermal discomfort. It encompasses a spectrum of consequences, including compromised human health, altered energy consumption patterns, and perturbations in ecological balances. Understanding and mitigating the UHI effect are essential components of sustainable urban development.

This research aims to investigate the Urban Heat Island (UHI) effect, focusing on the role of trees and vegetation in mitigating this phenomenon. By exploring UHI's multifaceted aspects and evaluating the effectiveness of green infrastructure, the study seeks to inform evidence-based strategies for creating resilient and nature-integrated urban environments. Subsequent sections will delve into UHI's definition, characteristics, contributing factors, and impacts on human health and the environment. The study also examines the relationship between UHI and climate change, incorporating the heat vulnerability index. The literature review highlights studies on UHI and emphasises the role of trees and green spaces. Following this, the report analyses existing initiatives in Australia, evaluating their effectiveness and identifying areas for improvement. The report concludes with an exploration of the specific benefits and mechanisms of trees and vegetation in mitigating UHI, emphasising their contribution to achieving net-zero developments and promoting sustainable urban landscapes.

The objective of the report is to:

- Define the urban heat island effect and describe its characteristics.
- Identify and explain the factors contributing to the urban heat island effect.
- Discuss the impacts of the urban heat island effect.
- Present a brief literature review on the subject.
- Provide an overview of the role of trees and vegetation in mitigating the urban heat island effect.
- Provide an overview of existing initiatives, policies, and frameworks aimed at mitigating the urban heat island effect in Australia.
- Evaluate the effectiveness of the identified frameworks.
- Identify gaps or areas for improvement in existing policies and strategies.

2.0 Urban Heat Island Effect

2.1 Definition and characteristics of urban heat island effect

The Urban Heat Island (UHI) is an effect where urbanised areas achieve higher air temperatures and surface temperatures than surrounding rural and undeveloped areas. This temperature difference is significant and measurable, often exceeding 5 °C. The UHI intensity is typically defined as the difference between maximum temperatures in the centre of an urban area compared to the surrounding areas.

Heat island effects can be characterised as surface heat islands or atmospheric heat islands. In practice both effects contribute to any urban heat island, but to varying degrees depending on the factors driving the heat island effect.

Surface heat islands form because urban surfaces absorb and emit heat to a greater extent than most natural surfaces. On a warm day, conventional roofing materials may reach 40°C warmer than air temperatures. Surface heat islands tend to be most intense during the day when the sun is shining.

Atmospheric heat islands form because of warmer air in urban areas compared to cooler air in outlying areas. Atmospheric heat islands vary much less in intensity than surface heat islands.

Surface temperatures vary more than atmospheric air temperatures during the day, but they are generally similar at night. The dips and spikes in surface temperatures over the pond area (Figure 1) show how water maintains a nearly constant temperature day and night because it does not absorb the sun's energy the same way as buildings and paved surfaces. Parks, open land, and bodies of water can create cooler areas within a city. Temperatures are typically lower at suburban-rural borders than in central urban areas.

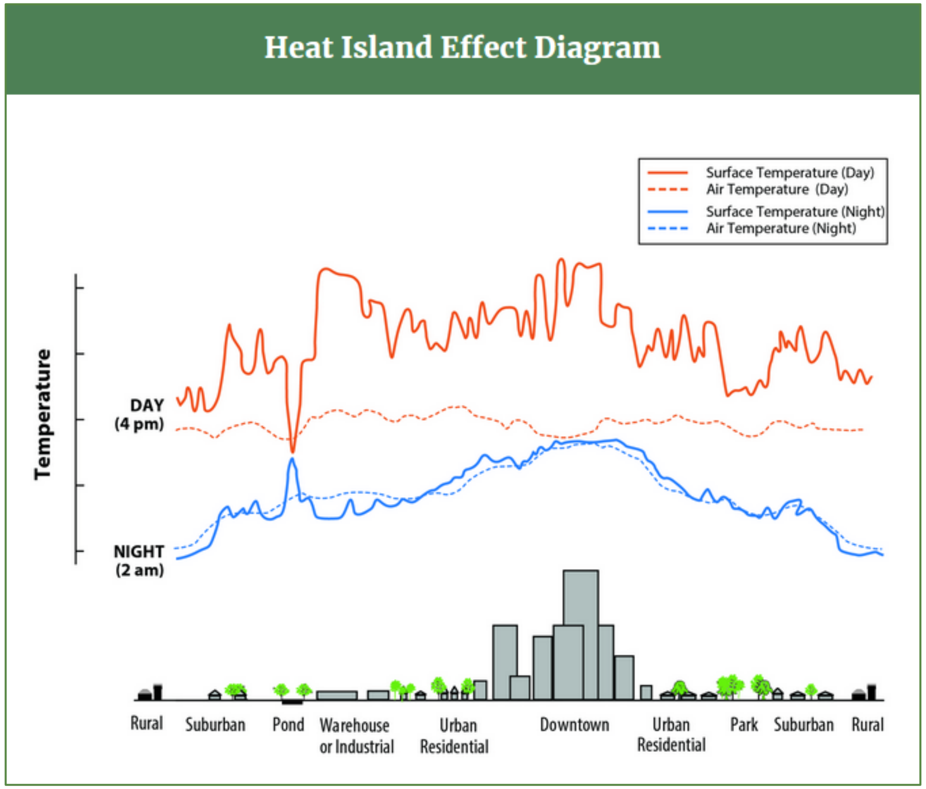

Figure 1: Heat Island Effect Diagram [1]

2.2 Factors contributing to urban heat island effect

Urban heat island effect is caused by several factors.

Buildings, roads, and other man-made infrastructure absorb and re-emit the more of the sun's radiation than almost all natural environments. Urban building materials such as asphalt, concrete, and steel have high thermal mass, which stores more heat than materials in natural environments and rural environments.

Densely developed urban areas create "urban canyons" of buildings, which reduce the sky view available for long wave radiation. At night, the reduced sky view causes dramatically reduced infra-red radiation from the urban centre to the night sky, effectively retaining more heat. Cities with tall buildings and narrow streets can block natural wind flows that would bring cooling effects. These effects, combined with the higher urban thermal mass, can significantly exacerbate heat retention.

Urban buildings are also indirect sources of heat; energy used for artificial lighting, air conditioning, appliances and office equipment is eventually rejected into the environment as waste heat. Similarly urban transportation and industrial activities emit heat into the urban environment.

The hard surfaces typically associated with urban environments tend to direct rainwater to stormwater systems, and away from the urban environment. In natural and rural environments, moisture stored in soil and vegetation naturally evaporates, creating a cooling effect. This effect is absent in urban environments, thereby contributing to the UHI effect.

Urban areas typically have higher levels of air pollution than urban and natural areas. Soot particles in air pollution can increase absorption of solar radiation, leading to slightly increased UHI effect. Localised CO_2 emissions may also contribute to localised warming, although there is little research on localised CO_2 emissions and associated localised warming, to date.

Other natural factors influencing UHI effects include geographical location and latitude, absence or presence of green space within the urban landscape, season and weather conditions, and global weather patterns (e.g. El Nino).

2.3 Impacts of urban heat island effect on human health and the environment

Urban Heat Islands lead to an increased risk of heat stress for the elderly, children, and persons in poor health. Similarly, there is increased risk of heat stress for outdoor workers and the poor, due to the lack of opportunity to escape heat waves. Heat stress is the highest cause of death from natural disasters.

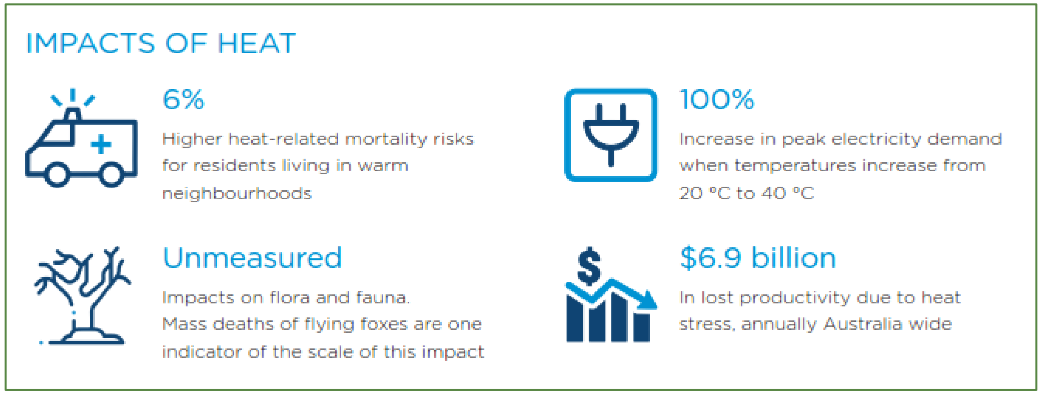

Figure 2: Heatwave Impacts [2]

Higher urban temperatures have been shown to significantly increase the concentration of harmful pollutants including ground level ozone, and airborne particulate pollution. Higher levels of ozone lead to greater incidence or severity of asthma, respiratory stress, emphysema, and other respiratory conditions.

Heat waves lead to increased risk of mortality in bats, birds, and reptiles, leading to those species moving away from urban/suburban environs.

Higher temperatures of surfaces and pavements can heat stormwater runoff, leading to poor water quality. Rapid temperature changes in aquatic ecosystems from warm stormwater runoff can be stressful or fatal to aquatic life.

2.4 Importance and impact of the urban heat island effect on urban environments

Increased daytime temperature peaks lead to greater demand for air-conditioning. Increased demand for electricity leads to premature wear and tear on both individual building electrical equipment and on electricity utility infrastructure. Increased consumption of electricity leads to increased CO_2 emissions for electricity markets with fossil fuel generation.

Increased overnight temperatures mean that building designed with nighttime heat purge and heat flushing systems are less effective. This in turn leads to increased reliance on electric cooling systems.

Heatwaves exacerbated by UHI have led to roads melting in Tasmania, the UK, Texas, and many other locations. The UK Road Surface Treatments Association (RSTA) now specifies that asphalt road pavements contain polymer modified binders which raise the bitumen melting temperature to 80°C. However the RSTA estimate that less than 5% of UK roads have so far been paved with the new specification mixture, and road melt incidents are now becoming common in UK summers.

Thermal inversions can occur in some cities, because of UHI. Usually, air is cooler the higher it gets in the atmosphere. But over an urban heat island, the opposite can happen, with warm air acting like a "lid". This traps smoke and pollutants at the surface, which can further increase temperatures, and causes serious health implications for city occupants. This effect occurs, for example, in Bangkok during winter [3]. If the inversion "lid" breaks, sudden rapid convection can trigger violent thunderstorms.

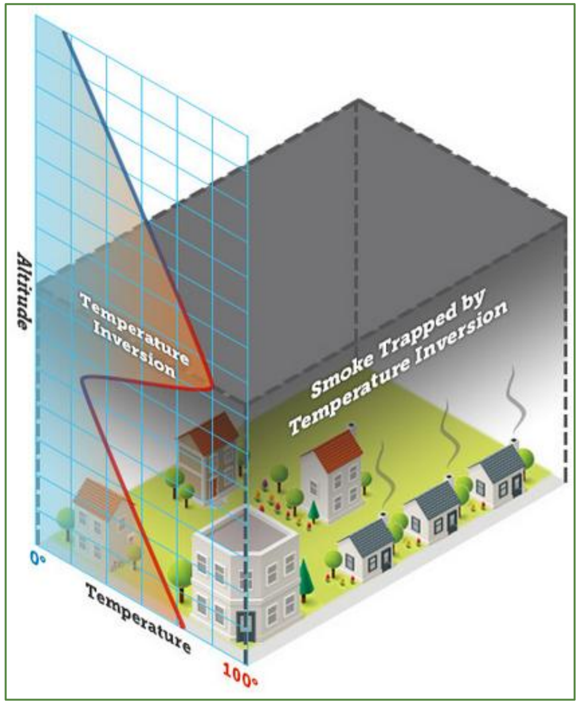

Figure 3: Temperature inversion [4]

In locations with urban or urban fringe electricity generation, the increased demand for electricity leads to greater localised airborne pollution from electricity generation.

2.5 Correlation of urban heat island with climate change and heat vulnerability

Urban Heat Island effects can lead to increased number of days with extreme heat in urban environments. Analysis by the US Environmental Protection Agency (US EPA) shows increased heat wave frequency, increased heat wave duration, increased heat wave intensity and longer heat wave seasons, correlated to increasing climate change.

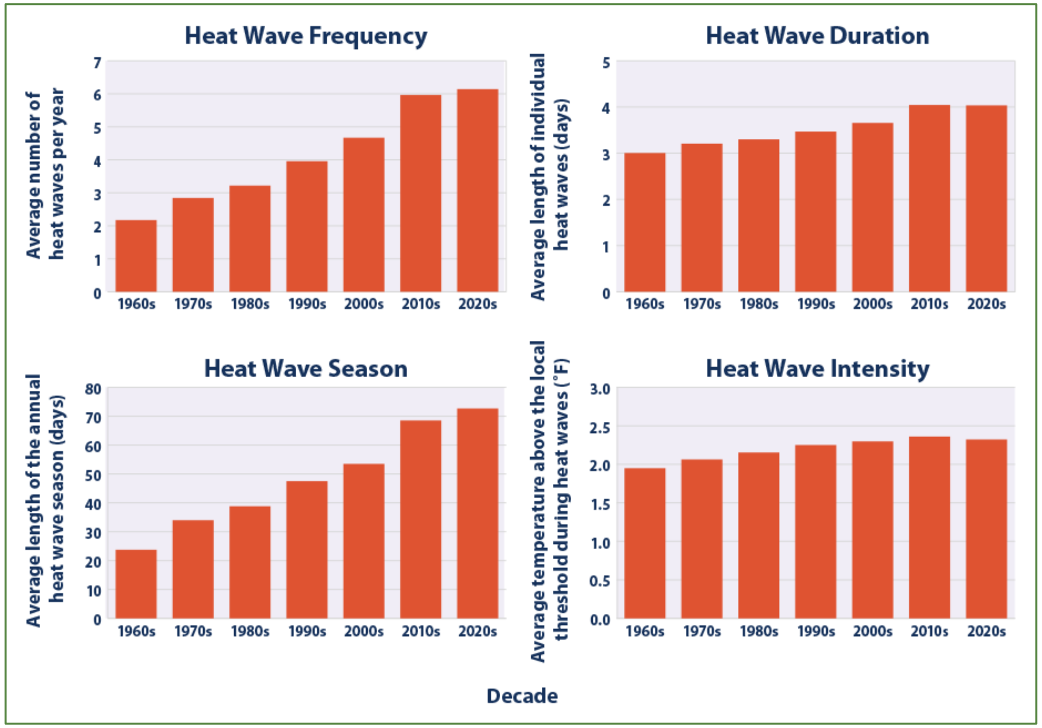

Figure 4: US heat wave characteristics, 1961-2021 [5]

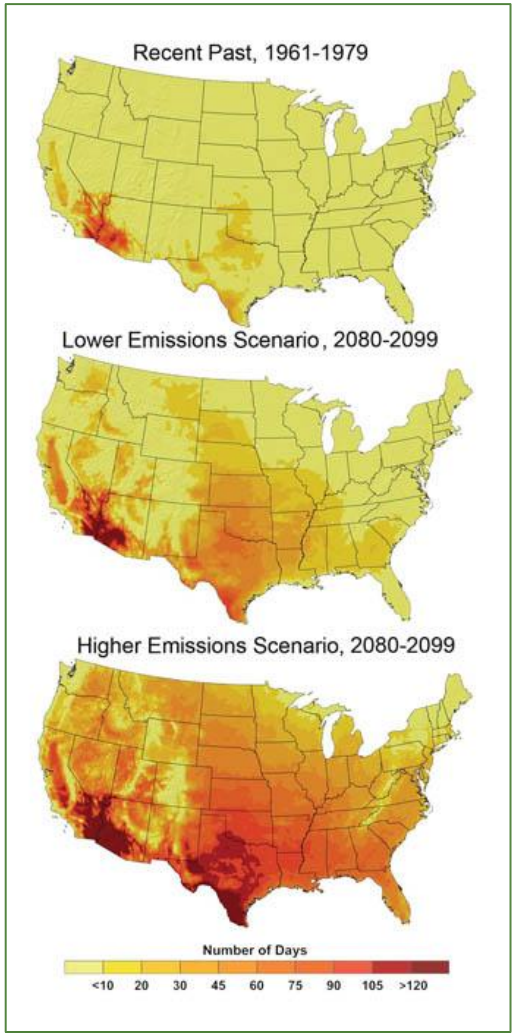

Figure 5: US EPA predicted annual days above 100 °F [6]

Modelling from the US EPA also shows an increase in the number of days in mainland United States where daytime temperatures exceed 100 °F (37.8 °C). The US EPA modelled two future scenarios based on a rapidly decarbonising world economy (Lower Emissions Scenario) and business as usual (Higher Emissions Scenario). Even with a rapidly decarbonising world economy, the frequency of days above 100 °F is expected to significantly increase.

Australian modelling [7] shows similar correlation between heatwaves and urban heat island effects, in some cities. In Melbourne and Adelaide, heatwaves are associated with stronger urban heat islands, leading to hotter nighttime temperatures. In Perth, however, the urban heat island effects are reduced during heat waves, exhibiting very rare urban coolth island effects.

2.6 Urban Heat Island Effect Mitigation Strategies

Urban Heat Island (UHI) mitigation strategies play a crucial role in addressing the escalating challenges posed by rising temperatures in urban environments. As Urbanisation continues to reshape landscapes, cities face the relentless onslaught of heat islands, where built-up areas trap and intensify heat, creating localised temperature spikes. To counteract this phenomenon, various strategies have been developed and implemented globally, aiming to cool urban spaces, enhance resilience, and mitigate the adverse effects of extreme heat on both the environment and human well-being. From the strategic incorporation of green infrastructure to the utilisation of reflective materials, these approaches are designed to alleviate the urban heat burden and foster more sustainable and liveable cities. The most common urban heat island effect mitigation strategies include;

2.6.1 Trees and vegetation

Increasing tree and vegetation cover lowers surface and air temperatures by providing shade and cooling through evapotranspiration. Trees and vegetation also reduce stormwater runoff and protect against erosion. Appropriate selection of deciduous species can provide seasonal shading, where suitable.

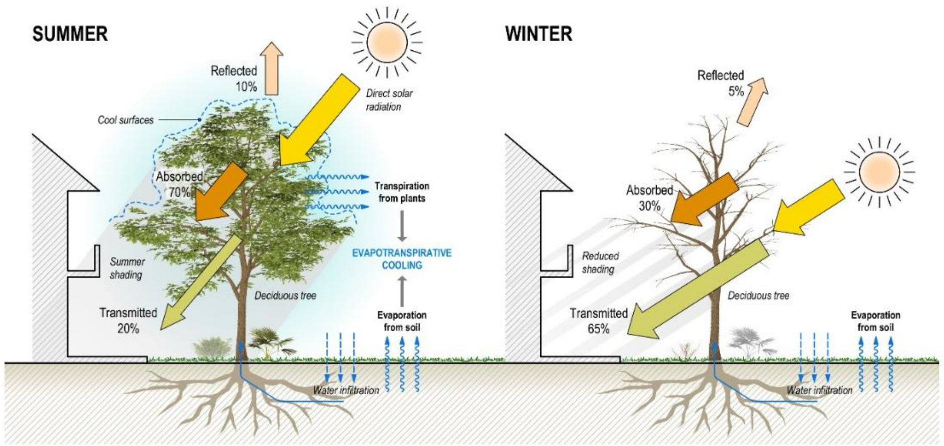

Figure 6: Schematic diagram of the cooling effects of a tree in summer and winter. [8]

- Trees can decrease ambient temperatures up to 4.0 °C [8]
- Urban trees and hedges can cause a peak ambient temperature reduction between 0.1 and 7.0°C and a median maximum temperature drop of 1.5°C [9]
- Surface temperatures of well-irrigated grasses can be up 15.0 °C cooler than surrounding paved areas, while dry grasses only up to 5.0 °C [8]
- An increase of 10% in tree canopy cover can decrease diurnal surface temperatures up to 1.05 °C in summer and 0.25 °C in winter [10]

2.6.2 Green Roofs

Also called “rooftop gardens” or “eco-roofs”, green roofs are roof systems that partially or completely covered with plants and a growing medium. Green roofs can provide solar and heat protection to buildings and contribute to decrease surface temperatures, improve indoor thermal comfort and decrease cooling energy demand of spaces directly below or separated by one or two floors from the roof. Green roofs can also contribute to increase local biodiversity, reduce the reflection from surrounding glazed surfaces, harvest rainwater for irrigation, and reduce stormwater runoff and peak flow rates. The cooling performance and effectiveness of green roofs depend on external factors such as climatic conditions (solar radiation, ambient humidity, wind speed, precipitation) and construction parameters (types and amounts of plants, depth of growing medium, irrigation levels).

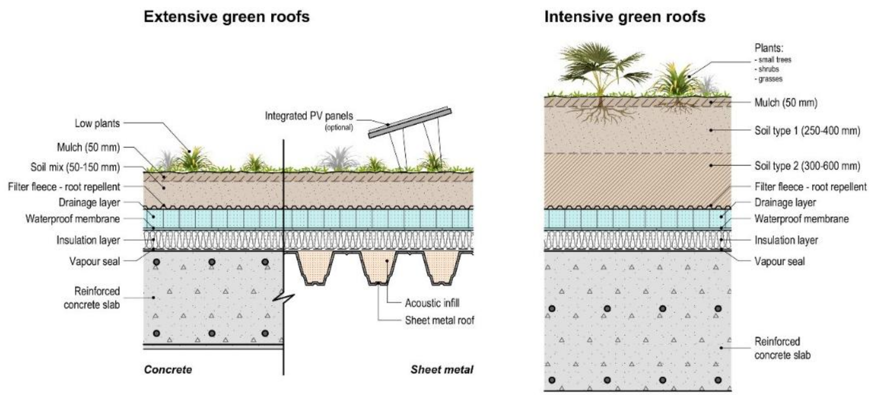

Figure 7: Schematic cross-sections of typical extensive and intensive green roofs. [8]

Figure 8: Example of green roofs [11]

- Green roofs can reduce surface temperatures between 5.0 and 15.0°C [8].
- Green envelopes can decrease indoor temperatures of spaces below roofs up to 2.0°C [8].

2.6.3 Green Open Spaces

Green open spaces (including trees in open spaces) have numerous benefits including climate moderation (reduction of air and surface temperatures), improved outdoor thermal comfort and amenity, increased biodiversity value, improved human health and social cohesion, energy savings, enhanced air quality, among many others. In this sense, green open spaces should be a primary aspect to consider in the design of any urban development, as it is highlighted as a mainstream strategy to mitigate UHI more effectively.

Figure 9: The crescent - Parramatta NSW [12]

- Well irrigated green open spaces such as parks can decrease radiant temperatures between 2.0 and 4.0 °C, and ambient temperatures between 1.0 and 2.0 °C [8].
- Grasses in green open spaces may decrease peak ambient temperatures between 0.1 and 3.0 °C and an average decrease of ambient temperatures between 0.1 and 1.0 °C [9].
- Green open spaces (parks) can decrease surface temperatures up to 15.0 °C [8].
- An increase of 10% in area of well-irrigated grasses can decrease diurnal surface temperatures up to 0.29 °C in summer and 0.13 °C in winter [8].

2.6.4 Vertical Greenery

Vertical greenery systems (VGS) –also referred as green/living walls– integrate plants onto buildings facades and other vertical structures. These can increase evaporative cooling and provide solar and heat protection (shade) by reducing surface temperatures, improving indoor thermal comfort of buildings and contributing to energy conservation. In addition, VGS can contribute to human wellbeing, regulate stormwater impacts, reduced water usage, increase local biodiversity, improve the efficiency of building integrated PV (BIPV), and increase property values and amenity for people.

Figure 10: Example of Green façade [13]

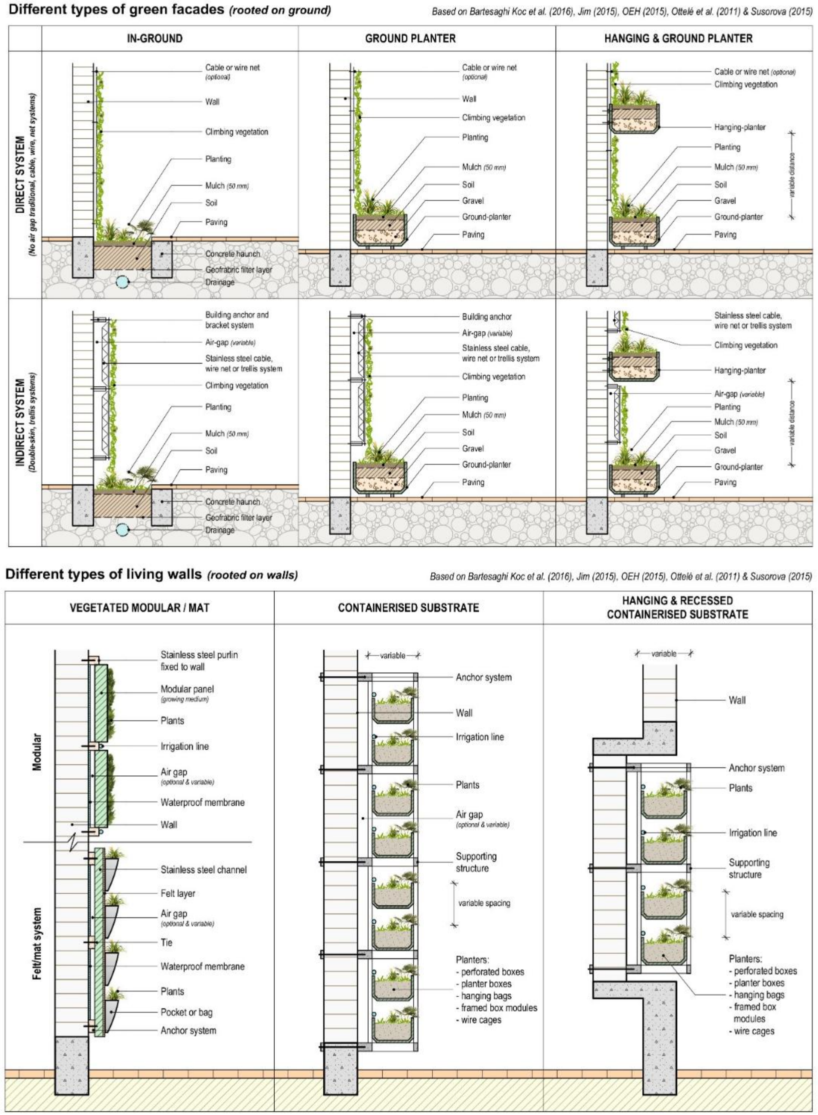

Figure 11: Schematic sections of different types of green facades and living walls [8].

- Green envelopes can decrease ambient temperatures up to 4.0 °C [8].
- Green envelopes can reduce surface temperatures between 5.0 and 15.0°C [8]
- Green envelopes can decrease indoor temperatures of spaces adjacent to walls up to 2.0°C depending on orientation [8].

2.6.5 Cool Roofs

Installing a roof with materials or coatings that significantly reflect sunlight and heat away from a building are referred to as ‘cool roofs’. This strategy reduces the amount of heat absorbed by the roof, which reduces roof temperatures, increases the comfort of occupants, and lowers energy demand.

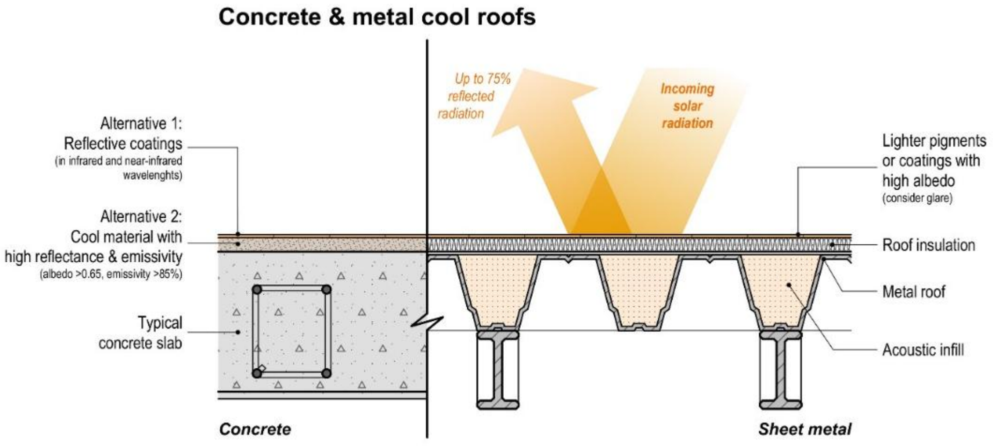

Figure 12: Schematic cross-section of typical cool roofs [8].

- An increase of 10% of albedo can reduce air temperatures between 0.23 °C and 0.62 °C [9]
- Cool roofs can decrease indoor temperatures of occupied spaces below between 1.2°C and 4.7°C. This corresponds with an energy reduction for air-conditioning between 18-34% in summer and temperate climate and an increase of 10% in winter required for heating [8].
- Cool roofs can reduce surfaces temperatures up to 33.0 °C [8].

2.6.6 Cool and Permeable Pavements

A cool pavement can be defined as a street pavement that absorbs less solar radiation than a traditional dark-coloured concrete or asphalt pavement. Significant advances in the development of ‘cool pavements’ have been achieved in recent years and two main technologies are already available to be implemented in urban development. On one hand, developments can apply cool pavements with a high solar reflectivity and high emissivity characteristics that cause a minimal glare effect on pedestrians. On the other hand, there are ‘water retention pavements’ that use the infiltrated water to decrease surface and near-surface air temperatures through evaporation. A detailed list of different cool pavements and technologies and their application on the built environment is presented in the ‘Guide to urban cooling strategies’ [8]. Adelaide performed a trial to evaluate the effectiveness of cool pavements in their “Cool Road Adelaide” trials.

Figure 13: Cool pavement project in Los Angeles [14]

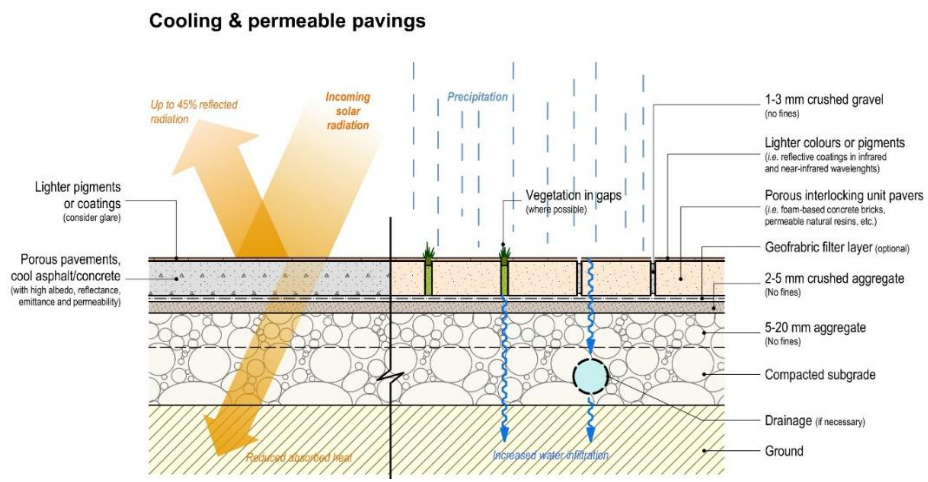

Figure 14: Examples and cross sections of cool and permeable pavements [8].

- An increase of 10% of albedo can reduce ambient temperatures between 0.27 °C and 0.9 °C [9].
- An increase of 10% of albedo of impervious surfaces can decrease daytime surfaces temperatures up to 0.18°C and night-time temperatures up to 0.22 °C[8]
- Cool pavements can decrease ambient temperatures up to 2.0 °C [8]
- Cool pavements can reduce surfaces temperatures up to 33.0 °C while permeable paving up to 20.0°C [8]

2.6.7 Cool Facades

Another technique to reduce heat emitted from buildings is to prioritise the use of cool or reflective materials on external facades with high emissivity, high albedo and high reflectivity properties. These can significantly reduce the absorption of solar radiation and thus, decrease the amount of heat emitted to the atmosphere, improve perceived outdoor and indoor thermal comfort, and decrease cooling energy demand.
An increase of 10% of albedo in façade materials can reduce air temperatures between 0.23 °C and 0.78 °C [9].

- Cool envelopes can decrease indoor temperatures of spaces adjacent to walls up to 2.5°C [8].
- Cool envelopes can reduce surfaces temperatures up to 33.0 °C [8].

2.6.8 Shading

Trees and vegetation that directly shade buildings or pavement can reduce the amount of heat absorbed and reradiated by those structures. Fabricated shade devices such as pergolas, arbours, shade-cloths and building eaves can similarly reduce heat absorbed from the sun.

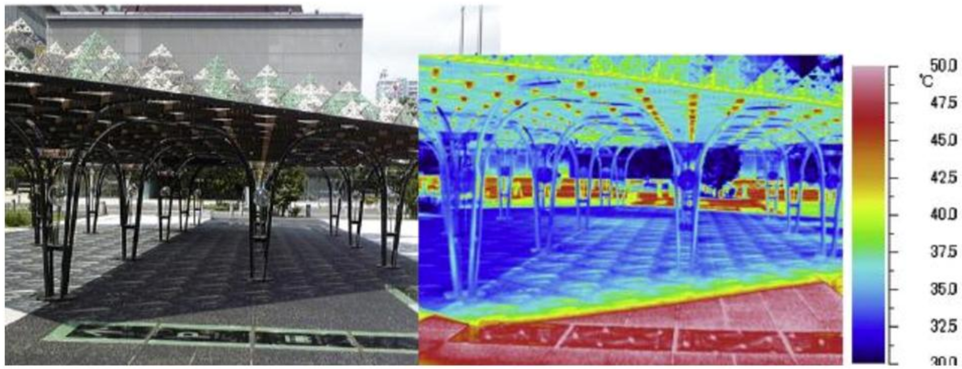

Figure 15: Shading device thermal image [15]

Figure 16: Types of shading structures [8]

- Shading devices can decrease surface temperatures up to 15 °C [8].

2.6.9 Water Features and Evaporative Cooling

The excess heat of the urban environment can be effectively dissipated by using natural heat sinks that usually present much lower temperatures than the surrounding ambient air. Water bodies act as major heat sinks as they are excellent heat absorbers, and along with natural ground cover (i.e. pervious surfaces), can be implemented for passive cooling dissipation to decrease cooling loads of buildings, reduce surface temperatures and improved outdoor thermal comfort.

Water features and sources (i.e. fountains, lakes, rivers, ponds, ocean, marshes, wetlands, etc.) are efficient in reducing surface temperatures during the day, especially large water bodies. As water needs energy to change phase from liquid to vapour, evaporative cooling refers to the process of removing heat from the atmosphere through evaporation.

In climates with relatively low humidity, outdoor water misters can be utilised to absorb latent heat from surrounding air, with a consequent large drop in local ambient temperatures.

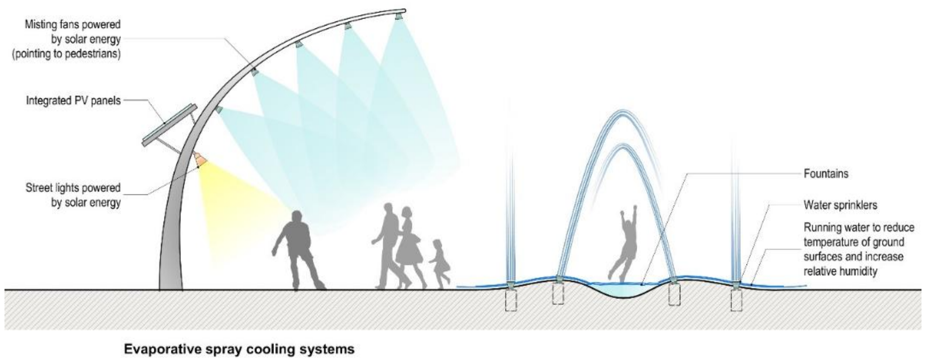

Figure 17: Schematic diagram of different evaporative cooling technologies [8].

Figure 18: Misting Poles [16]

- Surface/running water can decrease surface temperatures by at least 5.0 °C [8]
- Evaporative cooling systems can reduce ambient temperatures between 3.0 and 8.0 °C, while misting fans up to 15.0 °C [8]
- An increase of 10% in the area of water surfaces can decrease daytime surface temperatures between 0.86 and 1.37 °C and increase night-time surface temperatures between 0.15 and 0.39 °C [10]
- Water features can achieve a peak temperature reduction close to 4.5 °C [10].

2.6.10 Water Sensitive Urban Design (WSUD)

Water filtration, harvesting and treatment systems are essential components of WSUD that can contribute to mitigating UHI by ensuring evapotranspirative cooling and managing stormwater and rainwater for treatment and irrigation purposes. Key WSUD features include raingardens, swales or constructed wetlands, which are prescribed for new developments in planning control throughout Australia.

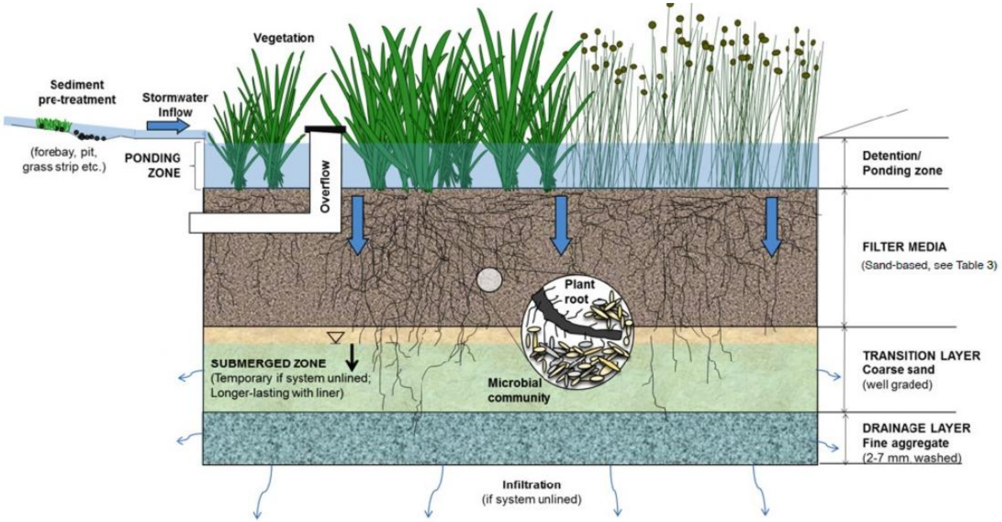

Figure 19: Essential components for stormwater biofilters

Figure 20: Examples of bioretention swale Source [17]

2.6.11 Built Form and Design and Street Orientation

Built form, design, and street orientation serve as effective urban heat island (UHI) mitigation strategies by influencing the thermal characteristics of urban spaces. Consideration of building heights, scales and masses to reduce urban canyons can impact ventilation and solar radiation. It is recommended to create a gradual transition of heights, scales and building masses between adjacent areas by designing and locating buildings of different heights in a way that adequate ventilation is provided to dissipate heat more rapidly to the atmosphere. Deep and narrow urban canyons should be avoided and although this may contribute to reduced solar exposure at certain times of the day due to overshadowing from buildings, it tends to trap more heat due to reduced ventilation and mutual reflection and absorption of radiation from building facets.

Fixed or movable sunscreens and shutters should be always provided in north and west-facing balconies and exposed concrete edge slab, full frame-less glass balustrades and exposed/fully glazed balconies should be avoided.

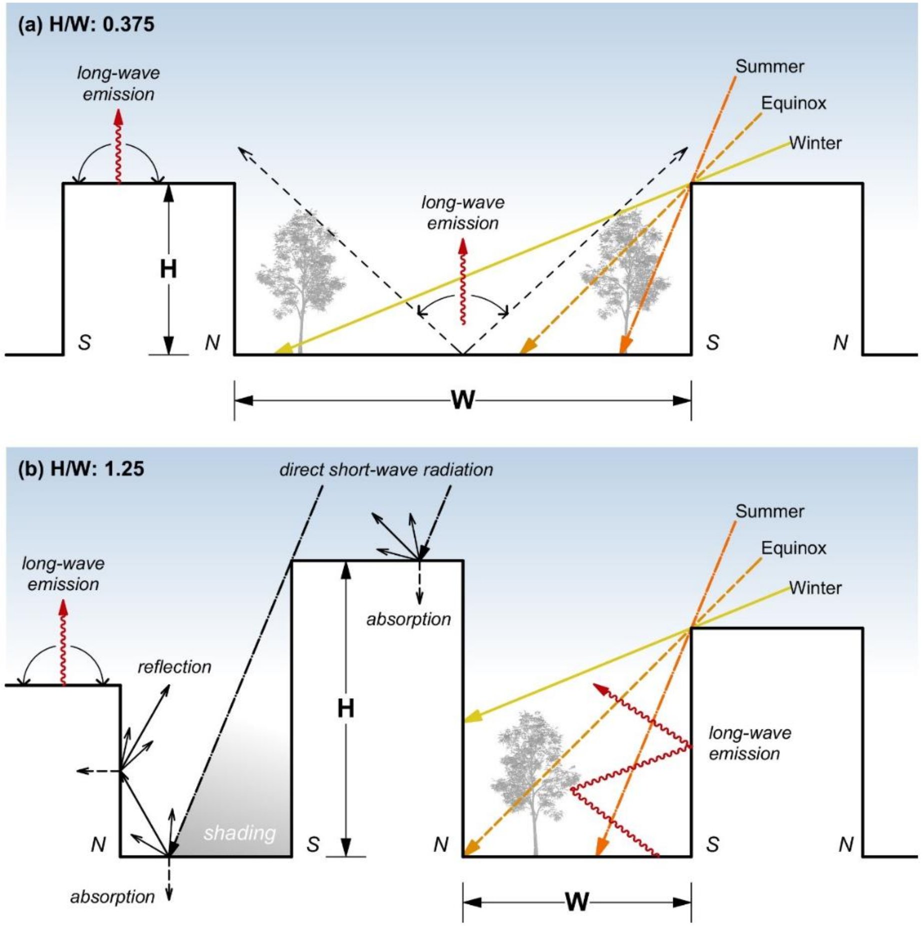

Figure 21: Common effects of urban geometry on the penetration, absorption and reflection of solar radiation at noon and in different seasons in (a) shallow and (b) deep urban canyons oriented East-West. (10)

- A cooling effect of 0.15 °C and 0.05 °C can be achieved during day and night respectively by decreasing H/D-ratio (ratio of average building height to the average distance between buildings [8].
- A decrease of 10% of building area can reduce daytime surfaces temperatures between 0.32 and 0.65 °C depending on the season [8].
- A decrease of 10% of building area can reduce night-time surfaces temperatures between 0.06 and 0.76 °C depending on the season [8].

3.0 Role of Trees and Vegetation in Mitigating Urban Heat Island Effect

3.1 Benefits of trees and vegetation in urban areas

Trees and vegetation in urban areas offer a wide range of benefits that extend beyond their aesthetic appeal. These green elements play a vital role in enhancing the quality of urban life, mitigating environmental challenges, and contributing to the overall sustainability of cities. This section highlights the substantial benefits that trees and vegetation provide in urban settings, drawing on current research.

Urban Heat Island Mitigation

Urban Heat Islands (UHIs) represent a growing concern in urban environments, as they contribute to elevated temperatures and associated problems. Current research underscores the importance of trees and vegetation in reducing UHIs. The shade provided by tree canopies, along with the cooling effect of evapotranspiration, helps lower surface temperatures and reduce the energy consumption required for cooling. Studies have demonstrated that strategically placed trees can lead to a significant decrease in local temperatures, making urban areas more comfortable during heatwaves.

Air Quality Improvement

Urban air quality is a critical concern due to the concentration of pollutants in densely populated areas. Trees and vegetation act as natural air filters by capturing airborne particles and absorbing pollutants. Current research highlights that urban greenery can substantially improve air quality, reduce the risk of respiratory illnesses and enhancing the overall health of urban residents.

Biodiversity and Habitat Enhancement

Urban areas are often characterised by limited green spaces, making it challenging for wildlife to thrive. Trees and vegetation provide critical habitat for various species of birds, insects, and small mammals. Recent research emphasises the importance of urban green spaces in supporting biodiversity. These green areas can serve as corridors for wildlife movement, helping maintain ecological balance within cities and preserving local flora and fauna.

Stormwater Management

Urbanisation can lead to increased surface runoff, which may cause flooding and water quality issues. Trees and vegetation are instrumental in mitigating these challenges. Current literature highlights their role in stormwater management, with tree canopies intercepting rainfall and vegetation aiding in water absorption. These natural systems reduce the strain on urban drainage systems and help prevent urban flooding, ultimately enhancing urban resilience to extreme weather events.

Enhanced Aesthetics and Well-being

The aesthetic appeal of trees and green spaces has a profound impact on the well-being of urban residents. Recent studies indicate that exposure to natural environments within urban areas can reduce stress, improve mental health, and enhance overall quality of life. Trees and vegetation in urban parks, streets, and public spaces provide opportunities for relaxation, recreation, and social interaction, fostering a sense of community and connection with the natural world.

Economic Benefits

Beyond their environmental and social advantages, trees and vegetation also offer economic benefits. Research demonstrates that urban greenery can increase property values, attracting investment and promoting local economic development. Moreover, the cooling effect provided by trees can lead to energy savings, reducing the costs associated with cooling systems.

3.2 Mechanisms by which trees and vegetation reduce urban heat island effect

Vegetation plays a pivotal role in mitigating the UHI effect through various mechanisms that contribute to the reduction of air temperature. The primary methods include direct shading of surfaces and the moderation of solar heat gain through evapotranspiration, where incident solar radiation is converted into latent heat. As a result, the ensuing lower temperature diminishes long-wave radiation emitted from the ground and leaves, creating a notable contrast with the heat-retaining properties of surrounding artificial surfaces and minimising radiant load on individuals.

The microclimatic impact of trees is achieved through various processes:

- Reduction of solar heat gain on land surfaces and building envelope through shading
- Reduction of the long-wave exchange with the sky as surface temperatures are lowered through shading
- Reduction of the conductive and convective heat gain by lowering dry-bulb temperatures through evapotranspiration during summer
- Increase of latent cooling by adding moisture to the air through evapotranspiration

Shading

Shading helps lower surface temperatures by blocking or diffusing incoming solar radiation. Surfaces such as asphalt, concrete, building facades and roofs, prevalent in urban areas, absorb and retain heat, contributing to elevated temperatures. By providing shade, these surfaces experience reduced exposure to sunlight, leading to lower temperatures and a subsequent decrease in the overall UHI effect.

Tree canopies and vegetation cover block solar radiation from reaching these surfaces reducing the air temperature. In general, trees are effective at blocking 70 to 90% of solar radiation in the summer and 20 to 90% in the winter.

These cooler shaded surfaces reduce the heat transmitted into buildings or re-emitted into the atmosphere. A study measured maximum surface temperature reductions due to shade trees ranging from 11-25° C for walls and roofs at two buildings. Another study examined the effects of vines on wall temperatures and found reductions of up to 20°C. The following image shows a thermal image in Melbourne demonstrating the difference in temperature between unshaded and shaded surfaces at street level.

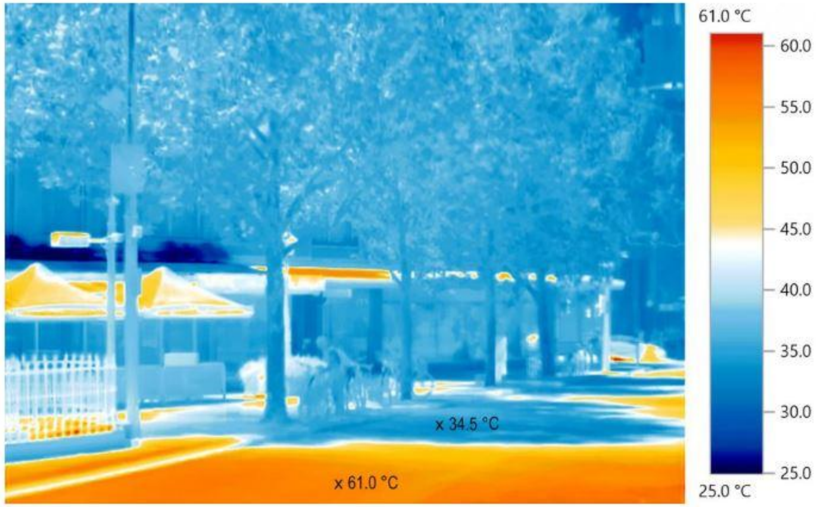

Figure 22: Thermal image showing shading effect on surface temperature [18]

This reinforces the importance of urban greenery as an effective UHI mitigation strategy. The effect adequate shading to urban areas has in contributing to this strategy are:

- Shortwave and longwave radiation blocked by plant canopy
- Less hat absorbed by building and ground surfaces
- Lower Surface temperature or canopy and turf
- Lower air temperature

Evapotranspiration

Vegetation helps reduce air temperatures through a process called evapotranspiration, in which plants release water to the surrounding air, dissipating ambient heat.

Evapotranspiration is defined as the combination evaporation (the transfer of water to water vapor on plant surfaces) and transpiration (the transfer of water to water vapor in plant cells). This process uses solar energy to convert water to water vapor, thus limiting the quantity of solar energy available to increase surface temperatures.

According to U.S. Geological Survey (USGS), an oak tree can transpire up to 151kL of water a year, while an acre of corn transpires up to 11.4kL to 15.1kL of water a day. This returning large quantities of water to the atmosphere and lowering air temperatures in the process.

Evapotranspiration is generally decreased when vegetation is replaced with an urban scape which evaporates less water and has fewer transpiring plants. Decreased evapotranspiration can contribute to elevated surface and air temperatures, thus contributing to urban heat island effect.

This reinforces the importance of urban greenery as an effective UHI mitigation strategy. The effect evapotranspiration has in contributing to this strategy are:

- Increases latent heat flux
- Decreases sensible heat flux
- Lower surface temperature or canopy and turf
- Lower air temperature

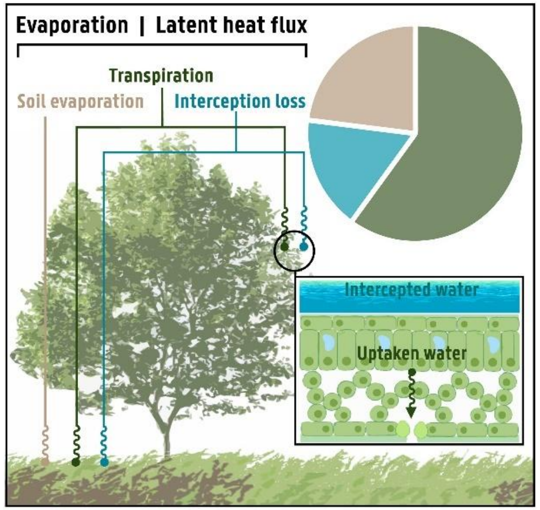

Figure 23: Evapotranspiration Diagram [19]

3.3 Factors influencing the effectiveness of trees and vegetation in mitigating heat island effect

The efficacy of trees and vegetation in mitigating the UHI effect is influenced by several factors intricately tied to the unique context of urban areas and the built environment. Understanding these factors is crucial for optimising the design and implementation of green infrastructure to mitigate rising temperatures in urban settings.

Species Selection and Canopy Coverage

The selection of tree and vegetation species plays a pivotal role in determining the effectiveness of UHI mitigation. Optimal canopy coverage is essential, as it directly influences the degree of shading and solar radiation interception. Strategically selecting species that thrive in urban conditions, with the ability to provide ample shade, enhances the overall cooling effect. Levels of evapotranspiration are impacted by the amount of water and energy present in the air and soil. The type of vegetation can also influence the levels of evapotranspiration. Species with extensive foliage or deep reaching roots transpire more. Also, ensuring adequate irrigation and quality soil are also contributing factors.

Urban Density and Layout

The layout and density of urban infrastructure significantly impact the penetration of sunlight and airflow. High-density urban areas with tightly packed structures can impede the effectiveness of shading and reduce air circulation. Integrating greenery into urban planning must consider the spatial arrangement to ensure maximum coverage and ventilation. The position of a tree impacts its effectiveness in cooling buildings, as trees located on the west or northwest sides of a building block the most solar radiation from reaching the building.

Land Use Planning and Green Spaces

Land use planning plays a pivotal role in determining the distribution of green spaces within urban environments. The strategic placement of parks, green belts, and street trees can significantly contribute to UHI mitigation. Well-distributed green spaces provide consistent cooling benefits across neighbourhoods and enhance overall urban resilience. Within the built environment context, developments must prioritise the integration of vegetation within their site boundaries. Ensuring significant landscaping coverage, prioritising deep soil planting, planting large canopy trees, green roofs and walls and integrating vegetation through the facades and terraces are examples of embedding UHI mitigation strategies into the design of new developments.

Maintenance Practices

Regular maintenance of trees and vegetation is essential for ensuring their long-term effectiveness. Pruning, watering, and addressing pest infestations are crucial tasks that contribute to the vitality of urban greenery. Well-maintained vegetation is more resilient and capable of providing sustained cooling benefits.

Climate Resilience and Adaptability

Urban areas experience diverse climatic conditions so selecting tree and vegetation species that are resilient and adaptable to local climates is imperative. Climate-resilient species can withstand temperature extremes, resist diseases, and continue to thrive under changing environmental conditions.

3.4 Vegetation contribution to achieving net zero developments

There is a direct link between climate change and UHI. Urban heat and the urban heat island effect are increasing the heat-related impacts of climate change in urban areas, making increased temperatures and extreme hot weather events more extended and severe. Within a holistic approach to respond to climate change, UHI mitigation and Net Zero developments are a crucial part of the strategy.

Net Zero refers to the balance between the quantity of greenhouse gas (GHG) emissions that are produced and the quantity removed from the atmosphere. In the context of urban development, vegetation can contribute to developments achieving this status through reducing operational energy consumption as well as for their carbon sequestration potential. Therefore, designing-in green infrastructure can contribute to achieving net zero developments.

As detailed in the previous sections of this report, the shading effect and evapotranspiration provided by trees and greenery significantly lowers ambient temperatures in urban areas. As a consequence, the demand for energy-intensive cooling systems decreases, leading to substantial reductions in operational energy consumption. Well-designed green infrastructure, including strategically placed trees and green roofs, acts as a passive cooling system, fostering thermal comfort and diminishing the reliance on mechanical cooling in buildings. This dual impact not only enhances the energy efficiency of structures but also contributes to the overall sustainability of urban developments. Studies [19] show that a 10% increase in tree canopy, green roofs and façade vegetation can contribute to a building's energy saving by 0.04 – 0.15kWh/m^2. This reduction in energy demand not only reduces the buildings CO2 emissions associate with its operation, but also results in lower energy bills for its occupants.

Beyond energy efficiency, vegetation plays a pivotal role in carbon sequestration, actively contributing to the offset of carbon emissions. Urban vegetation absorbs carbon dioxide from the atmosphere through photosynthesis and stores it in biomass of trunk, branches, foliage, stem, roots, and soils.

This inherent ability to sequester carbon not only aids in combating climate change but also aligns with the goals of achieving Net Zero developments. By integrating a diverse array of trees and green spaces into urban planning, cities can enhance their carbon sequestration capacity, mitigating the carbon footprint associated with urban living.

The carbon dynamics of urban forests reveals their capacity as both carbon storages and sinks. While growing forests demonstrate positive net carbon sequestration, this process slows as the forest matures. Notably, the maintenance of urban trees, albeit causing emissions, can be more effective in less intensively managed forest-like areas than in meticulously groomed park-like trees or street trees.

Studies [20] show that the net saving in carbon emissions that can be indirectly achieved by urban planting can be up to 18 kg CO_2/year per tree. Other metrics [21] reported an average of 21-29 Kg of CO_2 per m2 of tree cover. The 'London Energy Transformation Initiative' (LETI) published the 'Embodied Carbon Target Alignment' [22] work which aims to produce a standardised performance and reporting scope for embodied carbon. The benchmarks established in this work can serve as a basis to analyse the potential contribution of vegetation carbon sequestering in reducing a development's lifecycle emissions.

Embodied Carbon, A1-5, B1-5, C1-4 (inc. sequestration)

	Band	Office	Residential	Education	Retail
	A++	<150	<150	<125	<125
	A+	<345	<300	<260	<250
	A	<530	<450	<400	<380
RIBA 2030 Built Target	B	<750	<625	<540	<535
	C	<970	<800	<675	<690
	D	<1180	<1000	<835	<870
	E	<1400	<1200	<1000	<1050
	F	<1625	<1400	<1175	<1250
	G	<1900	<1600	<1350	<1450

All values in kgCO_2e/m^2 (GIA)

Figure: Embodied Carbon Benchmarks [22]

Although trees and vegetation have clear carbon sequestration potential and associated benefits in reducing emissions in urban areas, there are several considerations regarding the complexities of carbon modelling and the overall impact in the context of individual urban developments.

Research [23] on the carbon sequestration of urban trees usually excludes the carbon storage of urban soils, even though it has been demonstrated to have a significant impact on carbon storage. Studies show soil represents 64 % of the carbon storage in the human settlements compared to 20 % to associated with vegetation and 5% to buildings. soils in urban parks and lawns can store large amounts of carbon, which could exceed the amount stored in native grasslands, agricultural fields and boreal forests.

4.0 Literature Review

4.1 Review of relevant studies on the urban heat island effect and its implications

UHI effects are well known and broadly studied. Santamouris (2015) [24]compiled the results of 88 separate studies, which measured 101 cities in Australia and Asia. Their research found heat island effects ranging from 0.4 °C to 11 °C, with median of 4.1 °C. Santamouris (2016) [9] compiled similar results for 110 European cities, with heat island effects ranging from 1 °C to 10 °C, with median of 6 °C.
Kangning (2019) [25] showed that urban heat island effects cause summer land surface temperatures in Bangkok to be 10°C higher, on average, than surrounding countryside. The US Global Change Research Program (USGCRP 2017) [26] found that urban heat island effects contribute to climate change and, correspondingly, urban heat island effects are likely to become more significantly pronounced because of climate change.

Rogers, Gallant & Tapper (2018) [27] showed that Melbourne, Adelaide, and Perth are all affected by summer heatwaves and the urban heat island effect. However, their research specifically investigated the correlation between summer heatwave events and urban heat island effects. They find that Melbourne and Adelaide both experience exacerbated (warmer than normal) UHI at night during heatwaves, but Perth experiences diminished (cooler than normal) urban heat island effects during heatwaves, and often changes to an urban coolth island, when compared to non-heatwave periods.

Urban heat islands significantly increase the ambient temperature. Higher temperatures have a serious impact on the electricity consumption of the building sector increasing considerably the peak and the total electricity demand. Santamouris (2015) [28] analysed fifteen studies which showed that the increase of the electricity demand per degree of temperature increase varies between 0.5% and 8.5% and, on average, the cooling load of typical urban buildings is by 13% higher compared to similar buildings in rural areas.

Lai and Cheng (2009) [29] used statistical analyses to study air pollution under urban heat island effects Taichung City, Taiwan. Their results show certain weather patterns worsen the air quality and induce urban heat island effects. When Taichung is subject to these weather patterns, UHI appears and the concentrations of air pollutants (NO_2, CO_2 and CO) increase significantly ($P < 0.05$) with the UHI intensity. The convergence usually associated with nocturnal UHI causes the accumulation of air pollutants, thereby worsening the air quality at that time and also during the following daytime period.

Yoshikado and Tsuchida (1996) [30] show that increase of ozone at ground level can be primarily attributed to urban heating, and that predicted future ground-level ozone concentrations may be a threat to human health.

Perkins (2015) [31]provides many examples of heat stress leading to human mortality, including the 2009 Victorian heatwave which killed 374 people according to Victorian Department of Health data.

Nicholls et al. (2007) [32] reviewed public death records correlated to daily Melbourne temperature ranges. Their correlation study showed that when mean daily temperature exceeds a threshold of 30 °C (i.e. the mean of a day's maximum temperature and the subsequent night's minimum temperature), the average daily mortality of people aged 65 years or more is about 15-17% greater than usual. Similarly, excess deaths increase by 19-21% (over the expected death rate) when daily minimum temperatures exceed 24 °C .

Storms in urban areas direct heated stormwater and other pollutants from impervious surfaces, via drainage networks into streams, with well-described negative consequences on physical structure and biological integrity. Somers et al. (2016) [34] showed that water temperatures in urban streams rose rapidly by more than 7 °F (3.9 °C) during small storm events. Sudden changes in water temperature is well known to have harmful and sometimes fatal impacts to aquatic life.

4.2 Examination of the role of trees and green open spaces in mitigating the urban heat island effect

Adelaide Airport, SA Water and the CRC for Water Sensitive Cities (2018) [35] undertook a trial from 2015 to 2018, using stormwater to irrigate a 4-hectare site within the airport grounds. The trial used lucerne - a perennial pasture legume with deep root systems. Trial findings showed that air temperature in the irrigated area was more than 3 °C cooler than the non-irrigated area on hot days. On average the temperature difference was between 2.4 and 3.8 °C. Surface temperature differences were even higher than that recorded for air temperature. Many co-benefits were realised; improved ground cover meant soil erosion and dust erosion was reduced; the beneficial use of stormwater resulted in less water being discharged to the stormwater system and marine environment. Economic modelling also showed that the lucerne could be cropped, partially recouping the costs of irrigation.

Dubbo Regional Council and the CRC for Water Sensitive Cities (2019) undertook an urban heat island amelioration project in Bultje Street within Dubbo city centre. The project increases Bultje Street's tree canopy by 300%, by planting 14 street trees. The additional trees significantly increase asphalt shading during summer months. The selected trees were Japanese Elm 'Green Vase' cultivar, a deciduous tree, which maximises shade in warmer months and allows solar access in winter. Irrigation for the trees is provided by a dedicated stormwater catchment system. Each tree is sited in a tree pit, which reduces irrigation demand and reduces stormwater outflows thus reducing nutrient pollution levels within urban stormwater flows. The shading is expected to reduce asphalt temperatures under and near the trees from 58 °C to 38 °C during heatwaves.

4.3 Discussion of other benefits provided by trees and green open spaces in urban areas

McPherson and Muhnick (2005) [36] examined the relationship between tree shade and pavement performance in Modesto California. The roads in question were typically assessed on a rolling maintenance schedule and repaired with a slurry seal, as required (a slurry seal uses a mixture of water, asphalt emulsion, fine aggregate, and additives, to an existing asphalt pavement surface). Forty-eight sections of street were assessed according to the degree of tree shading. Unshaded street sections required an average of 6 slurry seals over 30 years; street sections with moderate shade from crepe myrtles required 5 slurry seals over 30 years; sections with dense shade from Chinese hackberries required only 2.5 slurry seals over 30 years. Costs for repaving were estimated to be 58% less for the densely shaded sections, compared to the cost of repaving for the unshaded sections.

The World Health Organisation (2016) [37] conducted a literature review with myriad reported health, mental health, and well-being benefits from urban green spaces, from 283 peer-reviewed papers and reports. Their review found that the underlying links between green spaces and health are complex and subtle, but unarguable due to the weight of evidence. Recognised benefits included;

- Improved relaxation and restoration, based on psycho-physiological stress reduction theory and attention restoration theory,
- Improved social capital - green space can play an important role in fostering social interactions and promoting a sense of community. There is a well-known protective effect of social relationships on health and well-being, while social isolation is a known predictor of morbidity and mortality.
- Improved immune system function - through exposure to diverse microorganisms in the natural environments which can play an immunoregulatory role. Japanese studies have demonstrated associations between visiting forests and beneficial immune responses, including expression of anti-cancer proteins.
- Anthropogenic noise buffering and production of natural sounds - evidence suggests that a well-designed urban green space can buffer the noise, or the negative perception of noise, emanating from non-natural sources, such as traffic, and provide relief from city noise.
- Vegetation (trees, shrubs, herbs and grass) can dampen the impacts of road traffic and industries and improve air quality in urban residential areas providing benefits for public health.
- Enhanced pro-environmental behaviour pro-environmental behaviour can be defined as “behaviour that consciously seeks to minimise the negative impact of one’s actions on the natural and built world”. In the face of climate change, which is projected to have serious detrimental effects on health, an upstream approach to minimising and mitigating its effects is to promote pro-environmental behaviour.
- Improved mental health and cognitive function – a study in Spain found that greater exposure to green space was linked to improved physical and mental health across all socioeconomic strata and genders. Individuals living in urban areas with more green space have been shown to have a reduced level of stress and improved well-being compared to controls with poorer availability of green space.
- Greater residential surrounding greenness has been linked with improved behavioural development (reduced difficulties, emotional symptoms and peer relationship problems) and reduced rate of Attention Deficit Hyperactivity Disorder in children.
- Reduced mortality – a study of pre-retirement age population in England showed evidence of the influence of the amount of green space in the neighbourhood on all-cause mortality. Studies in Japan have shown that the five-year survival rate in individuals aged over 70 was positively associated with having access to more space for walking and with parks and tree-lined streets near the residence.

5.0 Initiatives & Frameworks

5.1 Overview of existing initiatives, policies and frameworks aimed at mitigating the urban heat island effect in Australia

One of the impacts of climate change in urban areas has been increased temperatures and extreme hot weather events, increasing the intensity of urban heat and the urban heat island effect. It's therefore crucial for governments and authorities to address these issues by implementing comprehensive policies and strategies. This section provides an overview of the existing initiatives, policies and frameworks aimed at mitigating the urban heat island effect in Australia's largest urban centres.

These initiatives were assessed under the following categories:

- UHI reference: direct or indirect
    - Direct UHI reference relates to documents that address UHI directly as one of the key objectives.
    - Indirect UHI reference relates to documents where UHI is mentioned but isn't the main driving factor in the document.
- Focus on Vegetation: If the initiative's main focus is on green infrastructure.
- Effectives on UHI mitigation: An assessment on the initiative's main objectives and targets and their effectiveness on UHI mitigation
- Strengths and Weaknesses: The main identified strengths and weaknesses of the initiatives as it relates to UHI mitigation.
- Gaps or Areas for Improvement: Brief comments and suggestions on potential improvements on the initiatives to improve its effectiveness on UHI mitigation.

Refer to Appendix A for a complete review matrix of all the assessed frameworks, policies, and strategies. The matrix categorises the initiatives type, title and location, description and the above-mentioned assessment categories.

The following sections outlines key policies and frameworks, expanding the analysis in the Appendix.

5.1.1 Planning Schemes

Adelaide, Canberra, Melbourne, and Sydney planning schemes provide details on the Urban Heat Island (UHI) phenomenon. Among these, Canberra's strategic plan is evidence-based, incorporating specific information about the city's UHI. This plan is distinctive for featuring a recent map of land surface temperatures and specifying the measured UHI intensity in the city.

While Brisbane, Darwin, and Perth briefly acknowledge the UHI, Hobart's plan does not make any reference to either the UHI or heat events. In terms of addressing the impact on the heat-vulnerable population, Sydney's plan stands out as the only one describing how excess heat will affect the population, particularly the most vulnerable individuals and city systems. Also noteworthy is Melbourne's plan, which includes a projection of health costs attributable to the UHI.

Most planning schemes in Australia's major cities reference at least one measure aimed at mitigating urban heat, with a focus on urban greening. Adelaide, Canberra, Melbourne, and Sydney delve deeper into this aspect, providing detailed descriptions of suggested greening measures. These include the protection and management of urban forests and bushlands, the expansion of urban tree canopies, and the enhancement of Green Infrastructure to create a more extensive green grid or network.

The second most frequently mentioned heat reduction measure across the plans is the adoption of WSUD, referenced in many of the schemes. Adelaide, Brisbane, and Canberra explicitly state its application for UHI reduction, while Melbourne and Sydney cite its use for general cooling. Less emphasis is placed on other measures, such as climate-wise building design, the use of heat-reflective/cool materials, and the incorporation of heat reduction strategies through land-use planning.

Melbourne's recent planning scheme Amendment C376 incorporates proposed minimum mandatory ESD, urban cooling and green infrastructure provisions. It establishes planning control measures and minimum requirements for UHI response for all developments. The amendment sets minimum requirements for green cover and a minimum score under the Green Factor Tool.

Urban Heat Island Response

Table 5

Type of development	Requirement
All development	▪ Must provide the equivalent of at least 75% of the development's total site area as building or landscape elements that reduce the impact of the urban heat island effect. These elements include: • Green infrastructure • Roof or facade materials with a high solar reflectivity • Solar panels or shading structures • Hardscaping materials with a high solar reflectivity ▪ Should ensure non-glazed facade materials exposed to summer sun have a high solar reflectivity ▪ Should use passive cooling and heating techniques to reduce reliance on artificial heating and cooling ▪ Should utilise paving treatments which assist in cooling, such as permeable paving or light coloured aggregates, where applicable.

Figure 24: Extract from City of Melbourne Amendment C376

5.1.2 National Construction Code (NCC)

The National Construction Code (NCC) 2022, doesn't specifically address UHI but does set maximum solar absorptance values for roofs. This can contribute to controlling the among of solar energy absorbed by a roof and therefore help reduce increasing local temperatures. The code, however, allows for projects to use Performance Solution pathways where projects don't meet the maximum value.

<u>NCC 2022 Commercial (Volume 1)</u>

The National Construction Code (NCC) uses the solar absorptance (SA) value to classify roofing materials. Section J In Volume One of the NCC, (which primarily regulates multi-residential, commercial, industrial, and public assembly buildings), requires the SA of the upper roof surfaces to be not more than 0.45 to use the "deemed-to-satisfy" pathway to compliance. Alternatively, roof surfaces with SA greater 0.45 must use an NCC Performance Solution pathway for compliance.

<u>NCC 2022 Residential (Volume 2)</u>

Volume 2 of the NCC (which regulates smaller scale buildings including residential buildings, sheds, carports etc.) uses roof and wall SA values as energy efficiency design parameters in the "deemed-to-satisfy" elemental and NatHERS compliance pathways. Insulation concessions in warmer climates under the elemental pathway, and improvements to star rating in most climates under the NatHERS pathway, may be achieved by using lower solar absorptance external roof and wall colours.

5.1.3 Planning / Design Tools

Several Councils, state governments and universities have developed planning or design tools to facilitate incorporating UHI mitigation strategies in developments in the public and private realm. The following tools were found to be most relevant in UHI mitigation guidance tools.

<u>Green Factor Tool – City of Melbourne</u>

Green Factor is a green infrastructure assessment tool designed by City of Melbourne and developed to help with designing and constructing new buildings and significant alterations and additions that are environmentally friendly and include green infrastructure. Green Factor is free to use and available for the development industry to assess and benchmark their greening proposals. Embedded into the city's proposed Planning Scheme Amendment C376 Sustainable Building Design is a minimum requirement that all new developments must achieve a Green Factor score of 0.55. The score is provided based on the quantity and quality of vegetation in a development.

<u>Brisbane Green Factor (QLD)</u>

The Brisbane Green Factor is a framework developed by Brisbane City Council to improve green urban outcomes and strengthen the city's identity as a lush, sub-tropical city. Designed specifically for the local climate, it measures and promotes all forms of greening on development sites to support biodiversity, regulate urban temperatures, manage stormwater, enhance community wellbeing, and create a sense of place. While voluntary, it provides developers and designers with a consistent methodology to assess and optimise green infrastructure in projects ranging from residential and commercial buildings to public and community facilities. With Brisbane's rapid urbanisation and densification, the tool is intended to ensure that new developments contribute meaningfully to vegetation, ecosystem services, and long-term urban resilience.

<u>Cool Suburbs Tool – WSROC (NSW)</u>

Cool Suburbs is a rating and assessment tool for building heat resilience in urban planning and development, developed by the Western Sydney Regional Organisation of

Councils (WSROC). From precinct master plans to lot-scale design considerations, the Cool Suburbs Tool can be used to inform decision-making across the entire development process for both government and industry.

The Cool Suburbs Tool includes a rating system to assess the heat resilience delivered by urban designs at various development scales. The development of the rating system was supported by an expert science panel who developed the tool structure and credits.

Urban Heat Island Mitigation Performance Index

A project in collaboration between UNSW Sydney and Swinburne University, aims to develop a robust and tangible microclimate and urban heat island mitigation decision-support tool that bridges the gap between research on urban microclimates and its practical application. The tool provides governments and built environment industries with a decision-support tool to inform urban policy, development assessment and planning practices related to potential building and urban interventions, used to cool streetscapes and cities, decrease energy consumption, protect the population’s vulnerable health-wise, and improve conditions of comfort.

The tool ranks mitigation strategies based on effectiveness based on a project’s objectives, climate region, and type. Each strategy is supported with data on effectiveness, recommended provisions for design guidance, examples, and visual references. This is one of the seminal works related to UHI developed in Australia and should be referenced by built environment professionals and authorities.

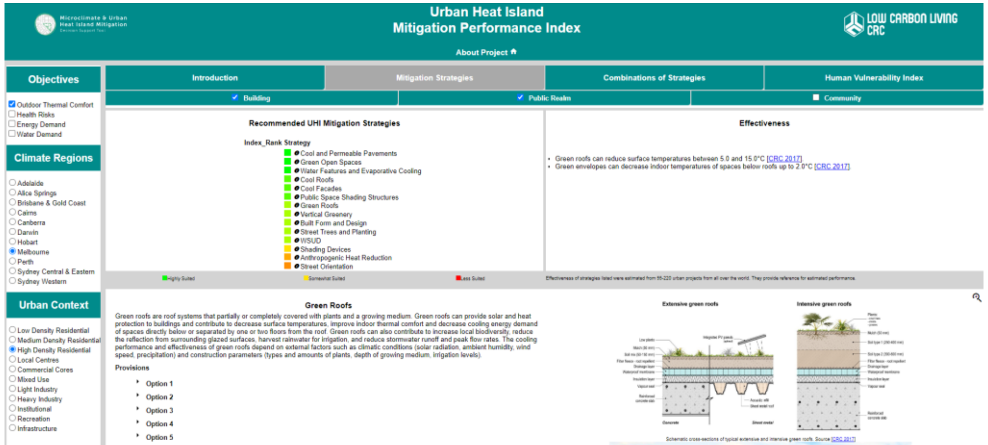

Figure 25: Urban Heat Island Mitigation Performance Index Tool

Green Star - Green Building Council Australia

Heat Resilience Credits

Developed by the Green Building Council of Australia (GBCA), Green Star is an Australian sustainability rating and certification system for the built environment.

The tools are composed of multiple categories, addressing building materials, systems, constructions process, indoor environments quality, energy efficiency and climate resilience. The rating scheme has minimum requirements and optional credits to achieve points required for a desired star rating, ranging from 1 to 6 stars.

Within the optional credits of the Green Star tools, one point can be achieved for reducing a development’s impact on the heat island effect.

Criteria:

At least 75% of the whole site area comprises of one or a combination of strategies that reduce the heat island effect.

The strategies that can be used to reduce the heat island are:

- Vegetation
- Green roofs
- Roofing materials, including shading structures, having the following:
    - For roof pitched <15°– a three-year SRI of minimum 64 or an initial SRI of minimum 82
    - For roof pitched >15°– a three-year SRI of minimum 34 or an initial SRI of minimum 39
- Unshaded hard-scaping elements with a three-year SRI of minimum 34 or an initial SRI of minimum 39
- Hardscaping elements shaded by overhanging vegetation
- Water bodies and/or water courses

Several planning schemes and guidelines that set specific targets and metrics, are aligned with the Green Star credit.

5.1.4 Planning & Technical Guidelines

Several planning and technical guidelines have been developed in Australia focusing on urban cooling, UHI mitigation, climate resilience and green infrastructure. The following is the most relevant and comprehensive plan assessed as part of this review.

<u>Guide to Urban Cooling Strategies – Low Carbon Living (CRC)</u>

This guide is one of the underpinning resources that many Councils adopted. It provides practical recommendations for experts and professionals in built environments aiming to optimise development projects in urban centres throughout Australia's climatic zones in order to moderate urban microclimates and minimise urban heat island impact.

It assesses the local climate, lowest to highest temperature and rainfall and ranks the cool paving, cool & green envelope and evaporative cooling to provide the most suitable solution for distinct Australian regions.

The following image shows a section of the guide rating the effectiveness of common UHI mitigation strategies for Australian cities.

City	Local climate		Record temperature (˚C)		Average rainfall (mm/y)	Cool paving			Cool envelope		Green envelope		Tree canopy	Evaporative cooling		Shading structures
	Summer	Winter	Min	Max		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	
Brisbane	Hot subtropical	Mild	2.3	43.2	1149	1	3	3	R-3 W-1	RW-3	3	3	3	1	2	3
Sydney	Hot subtropical	Cool	2.1	45.8	1221	1	3	3	R-3 W-1	RW-3	3	3	3	2	3	3
Parramatta	Hot continual	Cool	-1.0	45.5	964	1	3	3	R-3 W-1	RW-3	3	3	3	3	3	3
Canberra	Hot continual	Cold	-10.0	42.2	625	1	3	3	R-3 W-1	RW-3	3	3	3	3	3	3
Melbourne	Hot continual	Cool	-2.8	46.4	650	1	3	3	R-3 W-1	RW-3	3	3	3	3	3	3
Hobart	Warm	Cool	-2.8	40.8	621	1	2	3	R-2 W-1	RW-2	3	3	2	3	3	2
Adelaide	Hot continual	Cool	-0.4	46.1	566	1	3	3	R-3 W-1	RW-3	3	3	3	3	3	3
Perth	Hot continual	Cool	-0.7	46.2	855	1	3	3	R-3 W-1	RW-3	3	3	3	3	3	3
Darwin	Tropical	Mild	10.4	38.9	1703	1	3	3	R-3 W-1	RW-3	2	2	3		2	3
Cairns	Tropical	Mild	6.2	40.5	1999	1	3	3	R-3 W-1	RW-3	2	2	3		2	3

The matrix of climate-intervention set out above shows a summary of best-fit, useful and not applicable urban cooling strategies for selected Australian cities.

Roof	R
Wall	W

Effectiveness	
High	3
Medium	2
Low	1
Not applicable	
Negative	

Figure 26: UCS Matrix of Climate-Intervention (8)

5.1.5 Local urban cooling, greening and forest strategy

The research conducted as part of this review, demonstrated that most Australian Councils have a strategy on urban cooling, urban greening or heat island effect action plan. Overall, these strategies have similar goals and objectives and set out actions and responsibilities to achieve the identified goals.

The most comprehensive strategies outline specific targets and propose an extensive actions list for each short, medium and long term, with consideration to cost implications, as well as, governance, monitoring and review frameworks.

However, most strategies only present broad concepts and intentions to develop more specific targets and implementations plans. It was also identified that most plans that had established a specific timeframe for review, has not issued any updates or progress reports.

5.1.6 Urban Heat Mapping Tools

Another common tool adopted by major Australian urban centres is monitoring urban heat and developing web-based interactive maps available to the public. These are highly effective initiative to provide data and visual resources that can be used as guidance or support to address UHI by policy makers, developers and built environment professionals. The following are the most relevant heat mapping tools reviewed.

Heat Maps – City of Parramatta

The city of Parramatta Heat maps includes day and night thermal imagery for the area. The heat maps play a role in how the city plan a range of projects, including:

- The identification of areas to priorities for additional tree planting.
- The identification of areas which may be more vulnerable to increasing urban heat.
- The identification of areas which may require additional support in remaining safe and healthy in heatwave events.
- The selection of suitable areas to trial different technologies to combat urban heat.

Figure 27: City of Parramatta Heat Map

SEED Interactive Maps – NSW Government

This NSW Government interactive map provides a seria of datasets related to urban heat that can assist with identifying areas with higher heat vulnerability and lacking vegetation cover. In the context of UHI mitigation, three datasets can be viewed on the interactive map.

- Urban Heat Island Effect
- Urban vegetation Cover
- Heat Vulnerability Index

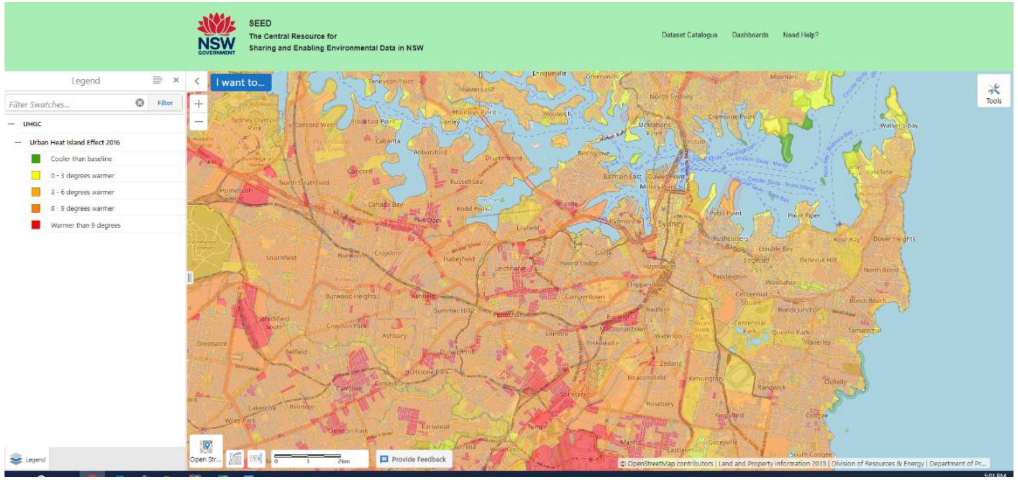

Figure 28: SEED Interactive Map

Cooling and Greening Melbourne Interactive Map Tool

This City of Melbourne interactive map provides a series of datasets related to urban heat that can assist with identifying areas with higher heat vulnerability and lacking vegetation cover. In the context of UHI mitigation, three datasets can be viewed on the interactive map.

- Urban Heat Island Effect
- Urban vegetation Cover
- Heat Vulnerability Index

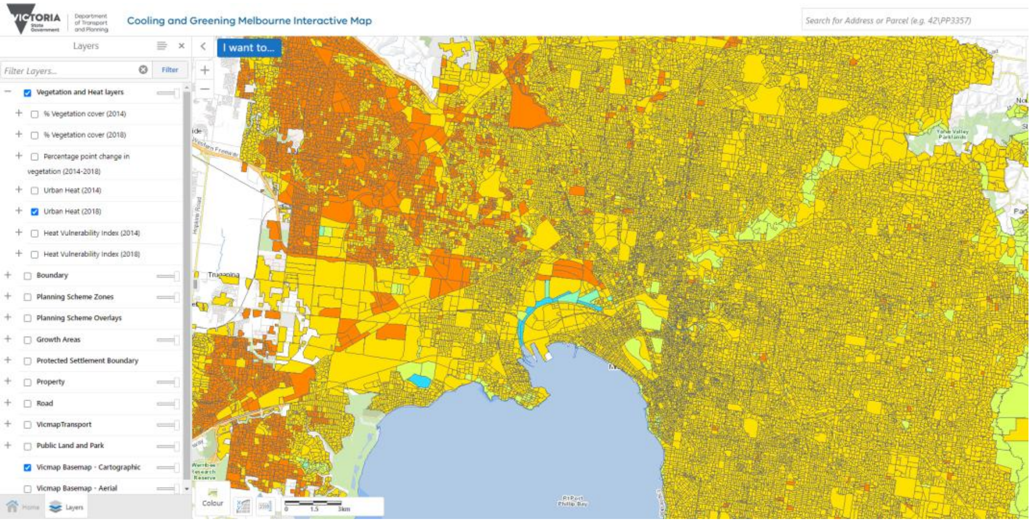

Figure 29: Cooling and Greening Melbourne Interactive Map Tool

Figure 30: The Rooftop Project

The Rooftop Project – City of Melbourne

This City of Melbourne interactive map (38) rates the potential for rooftops in the city where there may be opportunities to retrofit existing building rooftops for green roofs (intensive and extensive), cool roofs and solar panel installations. This can be an effective tool for developers and policy makers to identify potential strategies within the city.

5.2 Analysis of the effectiveness of these frameworks in reducing the urban heat island effect

The review of Australian urban heat island (UHI) mitigation frameworks demonstrates a wide spectrum of approaches—ranging from green building rating tools and planning schemes to council-led greening strategies and technical guidelines. While these initiatives collectively contribute to addressing UHI, their strengths and limitations vary considerably depending on scope, enforceability, and degree of integration with nature-based solutions.

Frameworks such as **Green Star (GBCA)** provide clearly defined metrics for UHI mitigation, particularly through credits addressing solar reflectance and green infrastructure. Their primary strength lies in the precision of design requirements, which enable measurable reductions in urban heat. However, because these credits are optional rather than mandatory, certification can still be achieved without addressing UHI. Additionally, supply chain gaps remain a weakness—many common materials lack published Solar Reflectance Index (SRI) data, complicating compliance. The Review Matrix notes that making such credits compulsory, or requiring vegetation-based solutions, would significantly enhance their impact.

Tools such as the **Green Factor Tool (City of Melbourne)** and the **Cool Suburbs Tool (WSROC)** embed UHI-focused criteria into design assessments. Their strengths lie in their specificity: they require targeted interventions like vegetation coverage or resilience scoring to achieve compliance, ensuring urban cooling is built into developments. Weaknesses, however, include limited geographic scope—currently applied only in select councils—and a high level of detail required at early design stages, which can challenge project feasibility. Appendix A highlights that these tools could be expanded nationally and streamlined with clearer guidance to improve usability.

The **Urban Heat Island Mitigation Performance Index (UNSW/Swinburne)** bridges research and practice, offering evidence-based recommendations tailored to climate zones and development contexts. While it provides a uniquely comprehensive resource, its high information volume can overwhelm practitioners unfamiliar with technical detail. The Review Matrix suggests this tool could evolve into a formal rating or assessment mechanism to standardise UHI mitigation across jurisdictions.

Guidance documents such as the **Guide to Urban Cooling Strategies (CRC for Low Carbon Living)** are seminal references underpinning many council strategies. Their major strength is accessibility: they provide practical, science-based recommendations, effectiveness rankings, and visual examples across Australia's climatic zones. Similarly, **Trees for a Cool City (CRC for Water Sensitive Cities)** and **Technical Guidelines for Urban Green Cover (NSW Government)** supply practical implementation advice, though both lack sufficient detail on species selection and long-term management. These gaps are noted in the Review Matrix as barriers to achieving optimised cooling outcomes.

Local strategies such as **Living Melbourne**, **Greening Sydney**, and the **Launceston Urban Greening Strategy** exemplify comprehensive, nature-based approaches that establish targets, timelines, and governance structures. Their strengths lie in holistic scope, integration of both public and private realms, and measurable targets (e.g., canopy cover percentages). Weaknesses are often related to governance and implementation—monitoring, funding, and accountability are inconsistently applied, and in several cases, reviews promised in earlier strategies have not been published. The Review Matrix highlights that while visionary, these strategies risk under-delivery without sustained enforcement and resources.

Planning Schemes and Amendments
Embedding UHI mitigation in statutory planning controls represents one of the strongest mechanisms for driving consistent outcomes. **Melbourne's Amendment C376** is exemplary, mandating minimum standards for green cover and albedo. In contrast, other jurisdictions adopt less prescriptive or broadly framed measures that lack measurable criteria. Weaknesses here include reliance on future updates or voluntary adoption, which can dilute the intended impact.

Urban Heat Mapping Tools
Heat mapping initiatives (e.g., **SEED NSW**, **Cooling and Greening Melbourne Maps**, and the **Rooftop Project**) provide valuable spatial data to identify hotspots and guide interventions. Their strengths include user-friendly, visual interfaces and direct application for planning and policy. Weaknesses lie in limited geographic coverage, with tools often confined to specific local councils. Expansion to a broader scale would amplify their utility and policy influence.

In summary, the reviewed frameworks demonstrate substantial progress in recognising and addressing UHI, particularly through green infrastructure and evidence-based planning. Their collective strengths include:

- Clear quantitative metrics in building rating tools.
- Science-based, practical guidance in technical documents.
- Holistic, nature-based goals in council strategies.
- Statutory enforceability in advanced planning amendments.

Conversely, weaknesses consistently identified across documents include:

- Non-mandatory status of critical UHI credits.
- Limited geographic scope of design tools and strategies.
- Gaps in implementation, monitoring, and long-term resourcing.
- Insufficient integration of detailed vegetation guidance, particularly species selection.

These findings underscore the need for greater harmonisation, stronger enforcement, and expansion of successful frameworks to ensure consistent and measurable reductions in UHI across Australian cities.

5.2.1 Assessment of the strengths and weaknesses of the frameworks

Green building rating tools are effective frameworks to ensure the implementation of sustainable practices within the built environment. In the context of urban heat, the credits aimed at UHI mitigation have clearly defined design requirements and metrics that can be incorporated into a design and are effective measures to reducing a development's impact on urban heat. These, however, are not mandatory credits (certification can be achieved without addressing UHI) and if targeted can be achieved without prioritising vegetation as a mitigation strategy.

The planning and design tools assessed in this study demonstrated the strengths outweigh the identified weaknesses. The more comprehensive tools provide high levels of information on the topic, as well as practical climate-specific applications that support built environment professionals in their designs and authorities to develop evidence-based policies and frameworks. For example, the Urban Heat Planning toolkit proposes draft amendments and clauses to current planning schemes and policies with specific targets and requirements.

There are also design tools that benefit from a more specific focus, such as the Green Factor Tool or the Cool Suburbs Tool. These require specific design interventions to meet their minimum criteria and scoring, which embed an UHI focused design into the built environment. These are still however, very localised tools applied formally on specific Councils in Melbourne, Brisbane and Sydney. These also require a high level of detail or information in a design which can be challenging for early-stage design assessments.

The reviewed planning and technical guidelines were identified as the underpinning documents referenced in most local strategies and frameworks. These seminal documents provide comprehensive science-based guidance and a holistic approach to UHI mitigation, in particular the Guide to Urban Cooling Strategies (Low Carbon Living CRC). The guide is highly informative and accessible to anyone, with extensive visual references and examples. The guide also lists technologies and strategies assessing their impact and effectiveness and provides specific guidance for Australia's major cities.

Almost all guides assessed had a focus on nature-based solutions and provided clear guidance for industry on how to implement these solutions across the private and public realm. Amongst the weaknesses identified were only the limited guidance on recommended plant and tree species on the Technical Guidelines for Urban Green Cover (NSW Government) and the lack of specific strategies or recommendations on how to improve and increase green infrastructure on the Greener Spaces Better Places documents which successfully documented the status of green infrastructure across Australia.

The local urban cooling, urban greening and forest strategies analysed from Councils across all Australian states share some of the same benefits and shortcomings.

Amongst the key merits are the strategies that address the private and public realm and contains extensive actions with specific quantitative targets and metrics with assigned responsibilities and a well-established governance structure, monitoring and evaluation processes. For example, the Living Melbourne document proposes a unified strategy across 32 Melbourne Councils with specific targets for tree canopy, and for canopy and shrubs, by region by 2050.

Most strategies, however, had a generic approach based on qualitative criteria and lacked more in-depth quantitative analysis, stronger commitments and more structured and specific actions and targets. Some only mentioned an implementation plan should be developed without defining any responsibilities and others required consideration of impacts on budgets and required funding for a successful implementation of the strategy. Also, the strategies that had set timeframes for conducting reviews and updates have yet to publish any new strategies.

Planning schemes and respective amendments share similar strengths and shortcomings. Embedding stronger commitments and specific targets to state and cities planning controls is the best way to ensure all new developments meet a certain standard and contribute to the reduction of urban heat impacts. Melbourne's amendment C376 stands out for including these specific requirements with clearly defined metrics and targets. Other states had either oversimplistic proposals and lack better defined parameters or only emphasises the necessity to update guidelines to include UHI mitigation strategies.

The urban heat mapping tools reviewed benefit from user friendly and interactive interfaces, showing specific data for the areas included. These, however, are still limited to the specific Councils, cities or areas or interest and could be expanded to other urban contexts that could benefit from the data and assessment.

5.2.2 Identification of gaps or areas for improvement in existing policies and strategies

From the perspective of achieving the objective of UHI mitigation, the efficacy of existing policies and strategies heavily relies on their ability to adapt and address evolving urban challenges. This section delves into a critical examination of existing initiatives, specifically focusing on the role of trees and vegetation as paramount elements in countering urban heat.

The examination of existing UHI mitigation initiatives has revealed significant gaps that, if addressed, could amplify the effectiveness of policies and strategies, particularly in harnessing the potential of nature-based solutions. One prominent gap lies in the lack of unified strategies from national, state and local governments. Although urban heat is a phenomenon with micro-climactic particularities specific to individual site context and constraints, the literature shows a limited range of UHI mitigation solutions with potential to be applied universally with distinct effectiveness.

The majority of these policies, strategies and initiatives would all benefit from establishing specific quantitative requirements with well-defined metrics and targets that must be applied by all developments and public realm projects. Integrating such prerequisites is essential for ensuring consistent and impactful UHI mitigation measures in all urban developments. This should also be complemented with an initiative to assess the existing building stock and propose a “retrofit for UHI mitigation” initiative to ensure a city-wide approach to urban heat.

It is widely recognised that increased urban greening is one of the most effective solutions to tackle urban heat related impacts. However, due to specific site conditions and constraints, nature-based solutions are not always feasible or the most effective. Therefore, aligned with the directive to impose more strict and mandatory requirements, more comprehensive and holistic frameworks for UHI mitigation should be implement, always focusing on green infrastructure, but including other urban cooling strategies, such as cool surfaces, shading structures, WSUD, evaporative cooling, etc. This will reduce the excessive number of similar initiatives across Australia and allow for a more concentrated effort with a simplified governance and funding structure to ensure these solutions continue to be implemented and increasing heat and climate resilience in urban centres.

6.0 Conclusion

This review confirms that the Urban Heat Island (UHI) effect poses a significant and growing challenge for Australian cities. Rising urban temperatures intensify health risks, increase energy demand, degrade air and water quality, and place added pressure on infrastructure and ecosystems. Addressing UHI is therefore essential to advancing sustainable, climate-resilient urban development.

The evidence demonstrates that increasing trees and vegetation is one of the most effective strategies for mitigating UHI, with co-benefits that extend to health, biodiversity, stormwater management, and social well-being. Research and case studies consistently show that green infrastructure lowers ambient and surface temperatures while contributing to net zero goals through energy savings and carbon sequestration.

Australia already has a wide range of initiatives, frameworks, and policies directed at UHI mitigation. Their strengths include the establishment of measurable planning controls (e.g., Melbourne's Amendment C376), comprehensive local strategies such as Living Melbourne and Greening Sydney, and technical guidelines that provide science-based design advice. However, the effectiveness of these efforts is undermined by several recurring weaknesses: limited enforceability, reliance on voluntary measures, gaps in monitoring and review, and inconsistent adoption across jurisdictions.

To strengthen impact, UHI mitigation frameworks need to move towards greater harmonisation, enforceable quantitative targets, and integrated approaches that combine vegetation with complementary cooling strategies. Expanding retrofit programs for existing infrastructure and embedding science-based guidance into statutory planning systems will also be essential for achieving meaningful, city-wide outcomes.

In conclusion, the findings of this report reinforce that expanding green infrastructure is not only critical to reducing the impacts of UHI, but also central to creating healthier, more resilient, and liveable cities. By adopting stronger, more consistent frameworks and investing in both new developments and existing urban fabric, Australia can significantly enhance its capacity to manage heat, support biodiversity, and deliver long-term climate resilience.

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Type	Organisation	Title	Description	UHI reference	Focus on vegetation	Effectiveness on UHI mitigation	Strengths & Weaknesses	Gaps or areas for improvement
Green Building Rating Tool	GBCA	Green Star	Green building rating tool developed by the Green Building Council of Australia to rate buildings, fitouts and precincts. All Green Star tools have a heat resilience or urban heat island effect credit that sets minimum percentage of site area for surfaces and materials that contribute to reducing the urban heat island.	Direct	No. Credit can be achieved with other compliant materials	Effective if targeted. Requirements align with a cool suburbs tool credit.	+ Clear design metrics defined for compliance. - Not a mandatory credit. - Not many materials have SRI data available which makes specifying products difficult for consultants.	Incorporate mandatory requirements to ensure every rated project addresses UHI mitigation.
	UDIA	EnviroDevelopment	Assessment scheme that independently reviews development projects and awards certification to those that achieve the required performance levels across selected elements such as ecosystems, waste, energy, materials, water and community. There is one credit aimed at reducing urban heat island effect which proposes commons means of UHI mitigation without any specific metrics.	Direct	No. Credit can be achieved with other compliant materials	Effective if targeted. Requirements align with a cool suburbs tool credit.	- Not a mandatory credit - No specific targets or requirements established. - Rating tool overall not to stringent and relatively easy to achieve a rating with common practices.	Implement prescriptive targets for addressing UHI. Turn credit into a mandatory requirement for all projects.
Planning/ Design tool	City of Melbourne (VIC)	Green Factor Tool	Green infrastructure assessment tool designed by City of Melbourne developed to help with designing and constructing new buildings and significant alterations and additions that are environmentally friendly and include green infrastructure. The green factor tool amendment is a supplement to Amendment C376.	Indirect	Yes. Tool exclusively assesses vegetation in developments	Contributes to UHI mitigation by increasing green infrastructure in developments	+ Specific focus on green infrastructure + Requires significant green coverage to achieve minimum score - Requires high level of detail on landscape design for accurate results - Currently adopted by only four Councils	More transparency on the weighting of each category to assist design teams on which areas need to be improved to achieve rating.
	WSROC (NSW)	Cool Suburbs Tool	Voluntary industry-based performance tool for place-based heat resilience. The CST has been designed for use by both developers and government, with the goal of supporting improved heat-mitigation outcomes.	Direct	No. However, the tool has credits that address green infrastructure	Highly effective, comprehensive science based tool developed to increase heat resilience in urban developments	+ Specifically developed for heat resilience + Has mandatory requirements to ensure minimum level of heat resilience is achieved. - Voluntary tool - Sydney western suburbs only - Interface isn't intuitive and framework design and structure is rather complex.	Possibility to expand to other states and cities. Simplify tool spreadsheet and provide further guidance, tutorials or examples for common development types in Australia.

Type	Organisation	Title	Description	UHI reference	Focus on vegetation	Effectiveness on UHI mitigation	Strengths & Weaknesses	Gaps or areas for improvement
	UNSW Sydney and Swinburne University	Urban Heat Island Mitigation Performance Index	Decision-support tool for governments and built environment industries to inform urban policy, development assessment and planning practices related to potential building and urban interventions, used to cool streetscapes and cities. The tool shows recommended UHI mitigation strategies suited for each Australian climate region and the urban context, evaluating the effectiveness of each strategy.	Direct	Yes, but not exclusively Comprehensive design support tool for meso and microclimatic solutions. Addresses green infrastructure and cool surfaces.	Highly effective as an educational tool which can be used to inform design decisions. Tool shows effectiveness of potential strategies for specific climate regions and development types	+ Support evidence-based decisions and strategies relating to low carbon and climate adaptation in urban development processes. + Provides information and recommendations tailored to development context + Fills the gap between research and practical application - High volume of information within the tool that can be overwhelming for certain stakeholders that aren't familiar with the topic.	There's potential to develop a rating system to evaluate development's impact on UHI mitigation. This could be used as a planning assessment tool for Council's and a design tool for project teams to assess if a project meets a certain standard of UHI mitigation.
	NSW	A Heat Vulnerability Index for Metropolitan Sydney	This tool can be used in conjunction with the UHI mitigation performance index. It measures the vulnerability of the population to extreme heat events in the metropolitan area of Sydney. The tool is used to assess heat vulnerability in specific areas, but does not make a connection or recommendations on how to improve the scenarios	Indirect	No. Credit can be achieved with other compliant materials	Effective as an informative tool to assess a site's context and to be used as guidance or support to address UHI.	+ Simple interface and Specific assessment - Applicable to Sydney only	The assessment could be integrated to one of the existing frameworks that propose solutions to heat vulnerability and could be expanded to other locations in Australia
	WSROC (NSW)	Urban heat planning toolkit	This toolkit intends to assist planners and local governments to make climate-conscious decisions and enhancing planning provisions to minimise the impact of urban heat. It prioritises resilience to urban heat and being able to amend LEPs and DCPs.	Direct	No. Increasing green infrastructure is mentioned but isn't the main focus.	This toolkit is effective in approaching UHI holistically and intends to assist planners and local governments to make climate-conscious decisions and enhancing planning provisions to minimise the impact of urban heat. It prioritises resilience to urban heat and being able to amend LEPs and DCPs.	+ Highly comprehensive and informative toolkit with a holistic approach to Urban Heat. + Proposes draft amendments and clauses to current planning schemes and policies with specific targets and requirements + Specific mentions for buildings and homes and Not just the public space and streetscapes. - As it's developed by the Western Sydney Regional Organisation of Councils it focuses on that region.	Potential to expand research and guidance for all states and regions and create a national strategy and guidance for UHI mitigation and climate resilience.
	City of Adelaide	Adelaide Design Toolkit	This toolkit well-defined the streetscape and landscape design in the city of Adelaide and its microclimate. Particularly, the greening toolkit defined the five planting schemes	Indirect	Yes, but not exclusively	Resources associated with the toolkit are currently under development. The section on urban greening will likely contribute to UHI mitigation.	+ Strategy to increase design standards in the public realm - No specific strategy addressing urban heat.	Potential to create more extensive guidelines tackling urban heat in the public and private realm.

Type	Organisation	Title	Description	UHI reference	Focus on vegetation	Effectiveness on UHI mitigation	Strengths & Weaknesses	Gaps or areas for improvement
Planning & technical guidelines	Low Carbon Living CRC	Guide to urban cooling strategies	The document is one of the underpinning resources that many Councils adopted. It provides practical recommendations for experts and professionals in built environments aiming to optimise development projects in urban centres throughout Australia's climatic zones in order to moderate urban microclimates and minimise urban heat island impact. It assesses the local climate, lowest to highest temperature and rainfall and ranks the cool paving, cool & green envelope and evaporative cooling to provide the most suitable solution. For example, in Brisbane, the best strategy for combating urban heat is to increase tree canopy and shading based on its unique microclimate. This document can be used in conjunction with Urban Heat Island Mitigation Performance Index.	Direct	Yes, but not exclusively	The guide provides an extremely detailed overview of the concepts and strategies within the Australian context. It also provides specific guidance based on effectiveness of mitigation strategies for Australia's major cities.	+ Comprehensive, science-based guide for urban cooling + Highly informative and accessible to anyone. + Extensive visual references and examples + Lists technologies and strategies assessing their impact and effectiveness + Specific guidance for Australia's major cities.	-
	NSW Government	Technical Guidelines for Urban Green Cover in NSW	This document provides practical guidelines of planning and implementing green roof, green walls, street tree planting, road surfaces and cool open spaces etc. for local government and build environment professional	Indirect	Yes	Guidelines offer built environment professionals a practical guide to incorporate more greenery into their designs, with the intent to mitigate the impacts on climate change, including UHI.	+ Clear guidance for industry on how to incorporate green cover in projects. + Recommendations for public realm and private developments + Typical construction details for every initiative covered in the report. - Limited guidance on recommended species	Could be complemented with a Plant selection guide and expanded to other Australian regions.

Type	Organisation	Title	Description	UHI reference	Focus on vegetation	Effectiveness on UHI mitigation	Strengths & Weaknesses	Gaps or areas for improvement
	CRC for Water Sensitive Cities	Trees for a Cool City: Guidelines for optimised tree placement	Tree planting is one of the most effective strategies to combat urban heat, especially street tree planting for the public realm. This document is one of the underpinning projects that provide a technical guideline on optimised tree placement to maximise the cooling effects. The tree placement location depends on the design and orientation of the streets. It is also linked with water management to ensure tree canopy retention.	Indirect	Yes	Highly effective technical guidance in UHI mitigation. The purpose of the document is to provide guidelines for optimised tree placement to maximise the cooling effects of street trees and deliver the largest benefits for human thermal comfort	+ Specific guidance for urban cooling + Clearly defined scope of study with practical recommendations - No specific guidance or recommendations on species selection.	Guidelines could be complemented with recommendations on trees species.
	Greener Spaces Better Places	Where should all the trees go? & Where will all the trees be?	The first document specified the performance and implemented action of every individual Council in Australia based on the vegetation cover. However, a Council with a great vegetation cover rate does not indicate how good their planning actions might be. The second document provided a snapshot of the performance of each state in Australia based on the VHHEDA vulnerability index.	Indirect	Yes	The organisations aim increase and improve Australia's urban green spaces. Helpful reports to assess the current state of green infrastructure in Australia to define specific measures to be adopted locally.	+Extensive review of the status of green infrastructure across Australia + Lists Councils based on VHHEDA Vulnerability Index - Doesn't propose specific strategies or recommendations to improve green infrastructure.	Potential to coordinate with Councils to propose a monitoring program of green cover and set Council-specific targets to improve and increase green infrastructure.
Local urban cooling, greening and forest strategy	The Nature Conservancy and Resilient Melbourne	Living Melbourne	Melbourne prepared a detailed plan that support Melbourne's strategic planning goals and visions. Victoria's Climate Change Adaptation Plan, which is highly relevant to the Living Melbourne plan, describes the actions the government will take to assist with adaption and coordination at various regional levels. A detailed urban heat mitigation strategy has been included. A discussion paper on Living Melbourne can be found here. The City of Melbourne developed an Urban forest strategy: making a great city greener which also endorse the Living Melbourne plan.	Direct	Yes, focused on increasing green infrastructure, biodiversity and resilience.	The strategy sets clear actions required for a holistic approach to UHI mitigation spanning across the public and private realm, governance and funding considerations.	+ Proposed targets for tree canopy, and for canopy and shrubs, by region to 2050 +Nature-based focused strategy with clear actions to achieve its objectives + Unified strategy covering 32 Melbourne metropolitan Councils + Actions provide a holistic approach for UHI mitigation and enhanced liveability, encouraging collaboration between sectors, funding and focused on enhancing green infrastructure.	Due to its comprehensive and holistic proposal of solutions, it may be challenging to monitor progress across all Councils.

Type	Organisation	Title	Description	UHI reference	Focus on vegetation	Effectiveness on UHI mitigation	Strengths & Weaknesses	Gaps or areas for improvement
	Victorian Government	Cooling and greening Melbourne	Guides and resources aligned with Melbourne strategy to address urban heat and increase green infrastructure. It's part of "Plan Melbourne" strategy to make Melbourne a more sustainable and resilient city.	Direct	Yes, but not exclusively. The plan includes guidelines to increase green infrastructure	It consists of a broad scope or works and guidance to address the city's resilience. If implemented, it will be effective in increasing green infrastructure and mitigating UHI.	+ City wide strategy to increase green infrastructure + Comprehensive and informative guidance for different urban scenarios - Not specific targets or metrics to be achieved	The plan could include ambitious targets and propose an ongoing monitoring of UHI to evaluate the effectiveness of the plan
	City of Sydney (NSW)	Greening Sydney Strategy	The city of Sydney has developed a comprehensive urban greening strategy that includes vegetation cover target, access to green spaces, cool street, green factor and a community engagement plan. This strategy adopts the green factor tool in Melbourne.	Direct	Yes, focused on increasing green infrastructure, biodiversity and resilience.	Similar to the Living Melbourne Strategy, the plan sets 6 key directions to achieve the city's development objectives.	+ Green cover targets established for 2050 + Nature-based focused strategy with clear directions and actions to achieve its objectives + Sets responsible parties and implementation timeline for each action.	Similar to the Living Melbourne strategy, the enforcing and monitoring of actions defined in the strategy may be challenging for a city wide approach.
	Lake Macquarie city Council (NSW)	Urban Greening Strategy	LMCC's urban greening strategy is undergoing development, which will be adopted by the Council in the short future. An online survey was filled by over 42000 residents to understand what the local residents care about the most and determine the priority of location to implement the greening strategy. This approach is fairly effective and targets the most urgent topics.	Direct	Yes, focused on increasing green infrastructure, biodiversity and resilience at a local Council level	Specific Council strategy addressing urban heat mitigation via increase of green infrastructure	+ Specific targets established for public and private realm + Monitoring and evaluating process established in the strategy +Alignment with UN SDG's + Timeframe, responsibility and resources provided for each action item - Only 3 main actions outlined in the strategy	For a holistic approach to UHI mitigation strategy could be combined with urban cooling initiatives, such as cool roofs and pavements.
	City of Launceston (TAS)	Launceston Urban Greening Strategy 2023-2040	City of Launceston has issued their draft urban greening strategy. It sets out the City's strategic vision for a resilient, connected and diverse urban forest. The Urban Greening Strategy aims to deliver a strategic greening approach that includes trees, shrubs, grasslands, structures (such as green roofs, walls, arbours) and other vegetation on public and private lands.	Direct	Yes, focused on increasing green infrastructure, biodiversity and resilience at a local Council level	Specific Council strategy addressing urban heat mitigation, biodiversity and social equity via increase of green infrastructure	+Specific targets established for green cover for 2040 + proposed implementation plan to measure, monitor and review targets. +Proposed review of strategy every 5 years + Proposed Governance structure	For a holistic approach to UHI mitigation strategy could be combined with urban cooling initiatives, such as cool roofs and pavements.

Type	Organisation	Title	Description	UHI reference	Focus on vegetation	Effectiveness on UHI mitigation	Strengths & Weaknesses	Gaps or areas for improvement
	Queanbeyan-Palerang Regional Council (NSW)	Urban Forest and Cooling Strategy	QRPC is one of the Councils that are leading the way to combat urban heat	Direct	Yes, focused on increasing green infrastructure, biodiversity and resilience at a local Council level	Specific Council strategy addressing urban heat mitigation, biodiversity and social equity via increase of green infrastructure	+Comprehensive action plan for short, medium and long-term actions with set responsibilities. + Supported by surface heat mapping report done in the area - No specific metrics or parameters to be monitored	Propose specific metrics and targets for green cover, biodiversity, cool roofs and pavements.
	Penrith City Council (NSW)	Cooling the City Strategy	The strategy integrates several aspects including green infrastructure, water sensitive urban design, policy and planning controls, and education to combat urban heat. It also identifies the responsibility of relevant agencies. Council's Organisational Performance and Development (OPD) Department will be monitor the implementation. Increase greenery and shading and installation of water features is the main strategy to mitigate the impact of urban heat. The study shows that more than 2 degrees can be reduced.	Direct	Yes, but not exclusively.	The Council strategy addresses a range of mitigation strategies, including green infrastructure, WSUD, increasing albedo, policy & planning and community engagement. An extensive list of actions are proposed for each short, medium and long term, with consideration to cost implications. It also sets a timeframe for review to monitor the progress.	+ Holistic approach to UHI mitigation + Consideration on cost implications + Consideration on monitoring - Most actions are broader and lack specific targets and metrics - The strategy had set a review for 2021 which has not been published,	Council has engaged in additional initiatives to tackle urban heat, such as the Cooling the City Masterclass and Heat Sensor project. However, the strategy could benefit from an update showing the progress made and lessons learnt over of the past eight years and issue a new strategy including more specific targets and a more detailed governance and monitoring framework.
	Gold Coast City Council (QLD)	Urban Tree Canopy Study	This study won the Landscape Planning category award at the 2020 QLD Landscape Architecture Awards and the 2020 National Landscape Architecture Awards. It prioritises planning and policy reviews. The street tree planting and streetscape development approval conditions will be under review. It sets a canopy cover target setting and prioritises on-ground urban greening actions. One of the documents used to underpin the development of the Urban Tree Canopy Study is CSIRO's Estimation of Land Surface Temperature and Urban Heat Island effect for Australian urban centres report	Indirect	Yes, but not as a means of UHI mitigation	The study proposes to evaluate the status of the Council's urban tree canopy cover. It identifies reducing UHI as one of the benefits as increasing canopy cover but recognises the study is a first step of evidence gathering.	+ Extensive information collected on Council's green infrastructure to be used in the future for setting targets - The study itself only covers the measuring of the current canopy cover and recommendations are more broad guidance on suggested next steps to be further investigated.	Follow up study or more comprehensive strategy could be produced based on the findings of the study. It should follow the recommendations of the study and propose a Council wide strategy for UHI mitigation strategies.

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	Moreland City Council (VIC)	Moreland Urban Heat Island Effect Action Plan	This action plan reviewed existing planning frameworks and policies and incorporate them with urban heat island mitigation. It indicates the promotion of vegetation cover and cool buildings, cool roads. In 2017 this plan won the Premier's Sustainability Award (Government Category).	Direct	Yes, but not exclusively.	The Council strategy addresses a range of mitigation strategies, including green infrastructure, WSUD, cool roofs and roads, policy & planning and community engagement. Key actions are identified assigning lead units and potential partners with consideration to the Council's budget and funding. It also sets a timeframe for review to monitor the progress.	+ Targets set for canopy cover increase and cool roofs in industrial buildings + Holistic approach to UHI mitigation + Sets specific measures, for the responsible parties with consideration to the Council's budget. - The strategy had set a review for 2021 which has not been published,	The strategy should be updated to reflect the current context of the Council. Merri Bek has seen significant new developments over the past years, which should be reflected in an updated UHI Action Plan. This should include specific quantitative targets for green infrastructure, measures for the public and private realm, clear definition of policies and planning requirements and a monitoring framework.
	City of Kingston (VIC)	Creating a Cool Kingston - Urban Cooling Strategy	The city of Kington acknowledges the importance of combating urban heat. It aims to increase tree canopy cover and integrate urban heat mitigation strategy in planning and building codes and guidelines, e.g. use of cool materials.	Direct	Yes, but not exclusively.	The strategy sets five strategic directions, including green infrastructure, planning and building, Council assets, emery response and community engagement. Despite covering the most common responses to urban heat, the plan doesn't provide specific measures or more in depth analysis and proposals on how these goals shall be achieved.	+ Holistic approach to UHI mitigation - Lacks specific targets and actions - States that implementation plan will be developed with no timeframe	A revised strategy and implementation plan shall be developed in accordance with the initial strategy commitments.
	City of Vincent (WA)	Greening Plan	This plan is mostly designed for public land vegetation. It sets tree canopy cover and indent to develop a green community.	Indirect	Yes, exclusively.	The plan five key objectives to improve the city's green infrastructure and community. Specific targets and actions established for each of the objectives and set timeframes for review. Although not exclusively developed for UHI mitigation, the outcomes of the plan, if implemented, shall be very effective.	+ Specific targets and actions for each of the identified objectives. + Detailed implementation plan, including yearly actions and reviews + Guidance on species selection for trees + Includes evaluation of previous plan	In the context of UHI mitigation, the city could benefit from a supporting strategy including measures beyond green infrastructure to include other mitigation strategies for a holistic approach.
	Greater City of Dandenong (VIC)	Urban Forest Strategy 2021 - 2028	The Urban Forest Strategy encompasses the Greening Our City: Urban Tree Strategy 2018-28 and the Greening our Neighbourhoods Strategy 2021-28, and considers the current issues and opportunities for canopy cover across the municipality	Direct	Yes, exclusively.	Similar to other Council strategies, it sets five key objectives including defining a framework for action, increased resilience, increase green infrastructure, community wellbeing and engagement. The Urban Forest Strategy acts as the parent document to the Greening Our City and Greening Our Neighbourhoods Strategies. The combined strategies set actions, timeframe, responsibility, indicators and resources.	+ Well defined timeframe, review and monitoring processes. - Several documents addressing the same issue. - No specific and quantitative targets established.	A unified strategy could benefit the Council by establishing specific targets and metrics for monitoring as well as governance and funding considerations.

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Planning and planning scheme amendments	City of Parramatta (NSW)	Local Strategic Planning Statement (2020)	The impact of urban heat island is acknowledged in the city of Parramatta's strategic planning. It is one of a few Councils that officially adopt urban heat in the planning documents. Urban heat stress is classified as Council policy direction, planning priority no.16.	Indirect	No	This Local Strategic Planning Statement provides strategic direction on how the City of Parramatta is planning for the next 20 years. It clearly set UHI mitigation as a priority, that will need to be addressed and further strategies created.	+ Implementation of UHI mitigation strategies into the planning scheme will ensure measures are formally required. - Only emphasises the necessity to update guidelines to include UHI mitigation strategies.	More details on specific UHI mitigation strategies could have been included in the statement.
	City of Melbourne (VIC)	Amendment C376 green cover standards	The amendment seeks to incorporate minimum mandatory ESD, urban cooling and green cover provisions in Melbourne's planning scheme	Direct	yes, but not exclusively	Planning control measure and minimum requirements established for UHI response for all developments. The amendment sets minimum requirements for green cover, a minimum score under the Green Factor Tool, increase albedo. Requirements also align with the Green Star credit.	+ UHI response mandatory for all developments + Clearly defined metrics and targets set	
	Brisbane City Council (QLD)	Major amendment package G (2021)	To minimise the impact of urban heat, a citywide rooftop garden initiative has been amended into the Brisbane planning scheme to ensure the rooftop garden is integrated into the overall building design. It promotes the provision of rooftop gardens that exclude from the maximum height of building in medium to high-density areas, which support the mixed-use of high-rise development.	Direct	Yes, focus on rooftop gardens	UHI mitigation is mentioned as the reason for the proposed amendment to increase rooftop gardens. However, unless more stringent or better defined targets are established, the proposal won't be as effective in UHI mitigation.	+ Facilitates developments integrating rooftop gardens - Overly simplistic proposal for 40% of roof are to be roof garden. - Unclear targets and definitions of rooftop garden - No consideration of solar photovoltaic panels in the area calculation	Propose more comprehensive set of guidelines and requirements to include UHI response to all developments.
Urban Heat Mapping Tools	NSW Government	SEED – Urban Heat Island Effect Maps (2021) SEED – Urban Vegetation Cover Maps (2021) SEED – Heat Vulnerability Index Map (2021)	Sharing and Enabling Environmental Data (SEED) map contains numerous datasets. It covers most areas in New South Wales. In the SEED map, you can view individual layers as shown in the examples or add all layers on the same map to use it interactively.	Indirect	N/A	Good source of information to inform authorities and guide policies and definition of strategies for UHI mitigation	+ User friendly interface and interactive map + Good source of information for micro, meso and macro city scale	

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	City of Parramatta (NSW)	Parramatta Heat Maps (2015)	Unlike the SEED map that only provides an overview of urban heat in NSW, the Parramatta heat map provide more detailed data specifically targeted in the City of Parramatta LGA. Day and night maps that allow you to identify urban heat hot spots very easily. In Benchmarking Heat in Parramatta, Sydney's Central River City, a thorough analysis of Parramatta's microclimate have been conducted.	Indirect	N/A	Good source of information to inform authorities and guide policies and definition of strategies for UHI mitigation	+ Council specific data + Heat map imagery possible to view individual lots + Presents day time and night time heat maps	
	Victorian Government	Cooling and greening Melbourne map	This interactive map covering Melbourne's metropolitan area shows the city's vegetation cover, urban heat and heat vulnerability index based datasets from 2014 and 2018.The dataset contains vegetation cover, urban heat, and the heat vulnerability index that can be used interactively.	Indirect	N/A	Effective as an informative tool to assess a site's context and to be used as guidance or support to address UHI.	+ Simple interface and Specific assessment - Applicable to Melbourne only	The map could be integrated to one of the existing frameworks that propose solutions to heat vulnerability and could be expanded to other locations in Australia
	City of Melbourne (VIC)	The Rooftop Project	The Green Our Rooftop project is one of the most important actions from Green our city strategic action plan 2017-2021. It provides an explorative GIS Rooftop Map interface with information around the potential of green rooftop and solar PV retrofitting in Melbourne.	Indirect	Yes, but not exclusively	This dataset shows where there may be opportunities to retrofit existing building rooftops for green roofs (intensive and extensive), cool roofs and solar panel installations. This can be an effective tool for developers and policy makers to identify potential strategies within the city.	+ User-friendly interface + Focus on the two main UHI mitigation strategies - Limited to City of Melbourne	Project could be expanded to surrounding Councils with high heat vulnerability index.
Building Guidelines	Brisbane City Council	Buildings That Breathe Design Guide	Both documents recognise the urban heat issue. By encouraging developers to adopt vertical greenery, elevated gardens and internal planting concepts to mitigate the urban heat island effect.	Indirect	No. Both documents provide more general guidelines for best practice buildings and urban design, which include green infrastructure.	Documents offer more general guidance on best practices for developments and doesn't highlight or enforce the importance of integrating UHI mitigation strategies	+ Best practice examples of completed projects - No Specific criteria or Recommendations outlined in the documents. - Generic guidance on General sections.	Produce more detailed and specific design parameters, initiative and metrics to be achieved in order to provide best practice guidance.

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Cool Pavement Initiative	Adelaide City Council	Cool Road Adelaide	This document specifies and provides a guideline on cool road sealants in Adelaide and can be used in conjunction with CRC for Water Sensitive Cities Scenario Tool.	Direct	No	Road surface temperature showed a reduction from approximately 3-9°C. However, the study was inconclusive in regards to air temperature impacts.	+ Practical application and trial of UHI mitigation strategy + Quantitative analysis of impacts on surface temperature + Study showed comparison with other nature-based UHI mitigation strategies + Community consultation process - Only three samples used	Continue assessment with future trials and other materials to assess impacts on a larger scale.

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