



RP2023: Microclimate and Urban Heat Island
Mitigation Decision-Support Tool
(Project Short Report)



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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
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- conclusions against results
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and provided constructive feedback which was considered and addressed by the author(s).

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1 Introduction

This project was carried out by UNSW Sydney and Swinburne University in collaboration with government and industry partners. This report briefly outlines the achievements of the project, incorporating several previously published reports and case studies (Craft et al., 2019; Ding and Craft, 2019) in addition to two new case studies in Parramatta and Macarthur Heights.

The main outcomes of the project include the following two online tools:

Microclimate and Urban Heat Island Mitigation Decision Support Tool

<http://uhimitigationindex.be.unsw.edu.au/uhitool/login.html>

Access is restricted. Login credentials can be requested from UHI-Index@unsw.edu.au

A brief video is available at <https://youtu.be/rcd7VYveu14>

Urban Heat Island Mitigation Index

<http://uhimitigationindex.be.unsw.edu.au/>

Entire tool is publicly available.

This report begins with project objectives, framework and identification of exemplar precincts for demonstrating the utility of the microclimate and urban heat island decision-support tool (UHI-DS Tool). The methods used for developing the tool are then described, followed by the key findings from three case studies that demonstrate the efficacy of the tool. Finally, the Urban Heat Island Mitigation Index is introduced, before concluding remarks are given on the project outcomes.

2 Project Objectives

The Urban Heat Island phenomenon is a major component of climate change as it impacts our cities. The challenge is real; in the Greater Sydney region studies have shown differences in temperature of as much as 6 - 10 degrees centigrade between eastern and western suburbs, and heat-related deaths in western suburbs can be up to three times higher than eastern suburbs during extreme heat waves (Santamouris et al., 2017b). Successfully planning and mitigating the effects of excess urban heat is crucial to dealing with future extreme heat events and developing healthy and liveable cities. Much research has been conducted, both in the CRC for Low Carbon Living and elsewhere, into analysing and treating urban heat island (UHI) effects. However, to date much of this research has been conducted on large scale domains and is unsuitable to support practical development guidelines at a precinct and building level. Consequently, developers and policy makers who do not possess the required technical knowledge to perform such analyses themselves are lacking the tools to effectively address this crucial challenge.

The CRC for Low Carbon Living (CRCLCL) funded a research project (RP2023) to address the gap between urban microclimate research and its practical application. The project aims to develop a robust and tangible urban heat island mitigation decision-support tool to support well-informed decisions about urban heat mitigation in a local context, and make accessible to government, developers and planners.

The project adopts urban development approaches to mitigate urban heat and answers the following research questions:

- Can innovative urban development approaches reduce the heat island effects and minimise the impact of increasing temperature extremes on outdoor thermal comfort, human health and energy consumption?
- To what extent do particular aspects of urban form, parks, greenery, waterways, building elements (e.g. facades, roofs) and urban heat mitigation techniques (e.g. evaporative techniques, reflective materials) help reduce urban heat island effects?

Hence, the objectives of the Urban Heat Island Mitigation Decision-Support Tool project include:

- Develop a systematic urban scenario analysis tool to inform development assessment, planning practices and urban policy related to potential building and urban interventions capable of urban cooling. The scenario analysis can be used to cool streetscapes and cities, reduce energy consumption, protect the health of the vulnerable, and improve thermal comfort.

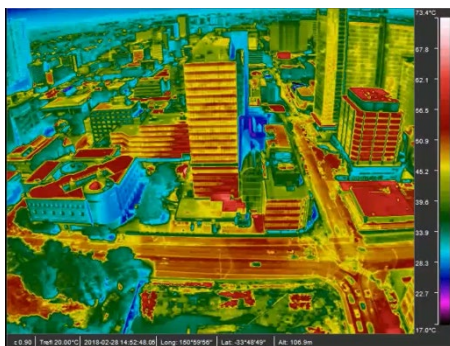
Table 1: Four exemplar precincts selected for demonstration of methods and utility of the UHI-DS Tool

Central Business District (CBD) Redevelopment	• Parramatta Civic Link	Parramatta Council	Western Sydney
	• Green Square Town Centre	Landcom, City of Sydney	Sydney
Greenfield Development	• Leppington	Stockland, Campbelltown Council	Western Sydney
	• Macarthur Heights	Landcom, Campbelltown Council	Western Sydney

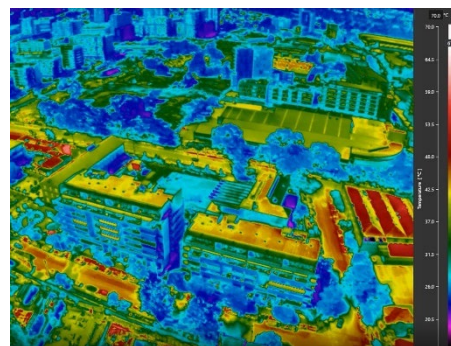
4.1 Microclimate Characteristics of Precincts

Characterising the microclimate of a precinct in relation to heat extremes is the first step in the analysis. It will identify urban overheating challenges in a precinct and assist in the development of mitigation strategies. Microclimate characteristics at a precinct scale comprise key variables such as air temperature and humidity, surface temperature, wind speed and direction, etc.

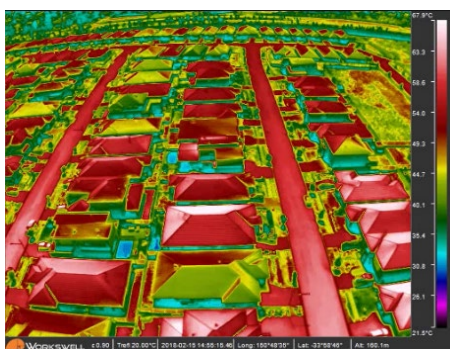
Figure 2 illustrates thermal environments of the four exemplar precincts collected over Sydney's 2017/18 summer, where different surface temperatures are represented in different colours. Examples of precinct-specific urban overheating challenges include the wide application of dark roofs in greenfield residential developments (Figures 2c and 2d), as well as built form and hard surfaces in the CBD redevelopments (Figures 2a and 2b).



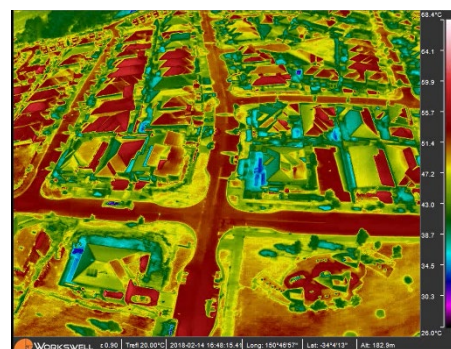
(a) Parramatta CBD



(b) Green Square CBD



(c) Leppington (Greenfield)



(d) Macarthur Heights (Greenfield)

Figure 2: Thermal environments of the four exemplar precincts.

4.2 Development Characteristics Precincts

Precinct development characteristics provide a local context for urban overheating mitigation analysis. There are different urban characteristics in Central Business District (CBD) redevelopments compared to greenfield developments, such as urban form, population, density, building type, public and private space and vegetation. It is critical to identify precinct development characteristics as they provide insight into the specific urban heat challenges of a precinct and suggest potential mitigation strategies. Figures 3 and 4 illustrate key development characteristics of CBD and greenfield developments using Parramatta and Macarthur Heights as examples.


CBD REDEVELOPMENT (PARRAMATTA CIVIC LINK)	PRECINCT DEVELOPMENT CHARACTERISTICS
 <p>Image: Parramatta City Council</p>	<ul style="list-style-type: none"> • Location: Project is bounded by Parramatta river to the North, Parramatta train station to the South, Marsden St to the West, Smith St to the East. • Municipality: Parramatta City Council • Zones: Includes both B3 Business Core and B4 Mixed-Use Zones • Land-use: Mixed-use area with heritage buildings, public spaces and plans for significant redevelopment of multiple sites • Proposed development: Two proposed pedestrian links for the future – Civic link and along Church St • Includes the Parramatta Light Rail corridor along Macquarie St and Church St • Population: Residential population expected to grow to 34,600 by 2036; Working population expected to grow to 83,000 by 2041

Figure 3: Examples of key development characteristics of CBD: Parramatta, Western Sydney


GREENFIELD DEVELOPMENT (MACARTHUR HEIGHTS)	PRECINCT DEVELOPMENT CHARACTERISTICS
 <p>Image: UNSW</p>	<ul style="list-style-type: none"> • Project area: 122ha • Location: The project is located alongside the Western Sydney University (WSU) campus at Campbelltown, with the site bounded by Narellan Road, the Hume Highway and the main southern railway line • Municipality: Campbelltown City Council • Delivery timing: 2014–2019 • Proposed residential lots: 966 lots • New residents: 2,460 • Zones: R3 – Medium Density Residential Zoning. • Stage 5 construction (future key development area for UHI-DS scenario analysis) starting mid 2018

Figure 4: Example of key development characteristics of greenfield: Macarthur Heights, Western Sydney

4.3 Main Challenges for CBD and Greenfields Redevelopments

Precinct development challenges vary based on urban overheating issues and precinct characteristics. For example, lack of urban vegetation, need for increased density to match the population growth, and poor outdoor thermal comfort during extreme heat days are main challenges for CBD redevelopments. Reduced private open (green) space, dark roofs, and increased reliance on air conditioning are main challenges for greenfield developments (Table 2). These challenges can be addressed through scenario analysis provided by the UHI-DS Tool.

Table 2: Examples of main challenges for CBD redevelopments and greenfield developments

MAIN CHALLENGES FOR CBD REDEVELOPMENTS	MAIN CHALLENGES FOR GREENFIELD DEVELOPMENTS
<ul style="list-style-type: none"> • Poor outdoor thermal comfort during extreme heat days: <ul style="list-style-type: none"> - <i>Reduced economic performance for street level retail and increased health risk for the vulnerable (elderly, children & disabled).</i> • Lack of urban vegetation: <ul style="list-style-type: none"> - <i>Less urban vegetation and green infrastructure due to urban form and change of land use, e.g. Parramatta CBD has a canopy coverage of 9% whereas best practice target for CBD areas is around 15% (Civic Link Framework, 2017); Green Square was previously an industrial precinct with minimal vegetation.</i> • Need for increased density to match residential and working population growth: <ul style="list-style-type: none"> - <i>To accommodate population growth and reduce urban sprawl, CBD precincts require significant increases in density, e.g. Parramatta CBD's residential population is forecast to be 34,600 by 2036 and its working population to be 83,000 by 2041 (City of Parramatta, 2017).</i> 	<ul style="list-style-type: none"> • Reduced private open space: <ul style="list-style-type: none"> - <i>Reduced private open space due to high concentrations of large detached dwellings on smaller lot sizes.</i> • Dark roof materials: <ul style="list-style-type: none"> - <i>Detached dwellings often have predominantly darker roof materials. There is a need for local governments and developers to endorse high performing cool roof materials through development guidelines and planning controls.</i> • Increased reliance on air conditioning: <ul style="list-style-type: none"> - <i>Limited places of relief from extreme heat for those without air conditioning and/or a swimming pool.</i>

4.4 Urban Overheating Mitigation Strategies

The UHI-DS Tool provides scenario analysis of urban overheating mitigation strategies to address precinct development challenges. It provides an interactive 3D visualisation platform capable of testing various urban overheating mitigation scenarios to support precinct development assessment and decision-making. The scenario analysis of mitigation options falls into two major categories – *built form* and *public realm* – to support urban overheating mitigation decision-making based on specific precinct development characteristics. In addition, the ability to query performance according to Green Star Communities credit criteria is provided. Table 3 shows the scope and examples of mitigation scenario options provided by the UHI-DS Tool for CBD and Greenfield developments.

Table 3: Example Scenarios of Urban Heat Mitigation Options for CBD and Greenfields Developments

EXAMPLE SCENARIOS FOR CBD REDEVELOPMENTS	
BUILT FORM	
<ul style="list-style-type: none">• Building Height<ul style="list-style-type: none">- <i>Parramatta Case:</i> Impact of existing and proposed building heights surrounding public spaces and along proposed pedestrian links.• Building Footprint<ul style="list-style-type: none">- <i>Parramatta Case:</i> Impact of building setbacks and footprints of future buildings along proposed pedestrian links.• Façade Materials<ul style="list-style-type: none">- <i>Green Square Case:</i> Impact of façade materials (high albedo, high emittance and green walls) for all proposed buildings over 6 storeys.• Roof Materials<ul style="list-style-type: none">- <i>Green Square Case:</i> Impact of roof materials (high albedo, high emittance and green roofs) based on Green Star Communities Urban Heat Credit requirements.- <i>Macarthur Heights Case:</i> Impact of light vs dark coloured roofs• Awnings<ul style="list-style-type: none">- <i>Parramatta Case:</i> Impact of building awnings (3m width and 4.5m vertical clearance) along proposed pedestrian links.	
<hr/>	
PUBLIC REALM	
<ul style="list-style-type: none">• Hard-Scape Surface Materials<ul style="list-style-type: none">- <i>Parramatta and Green Square Cases:</i> Impact of cool, permeable, high albedo, vegetated or light coloured pavements within proposed public spaces and pedestrian links.- <i>Macarthur Heights Case:</i> Impact of cool roads and pavements along proposed road network.• Water<ul style="list-style-type: none">- <i>Parramatta and Green Square Case:</i> Impact of the Parramatta River on the northern boundary of the CBD and impact of water misting within proposed public spaces and pedestrian links.- <i>Macarthur Heights Case:</i> Impact of waterbodies near precinct.• Vegetation<ul style="list-style-type: none">- <i>Green Square Case:</i> Impact of vegetation, trees, and landscaping design within the proposed public parks, plazas and streets.- <i>Macarthur Heights Case:</i> Impact of trees along proposed streets.• External Shading Structures<ul style="list-style-type: none">- <i>Parramatta and Green Square Cases:</i> Impact of external shading structures within the proposed public parks and plazas.	

5 Methods for Urban Heat Island Mitigation Decision Support Tool Platform

5.1 System Architecture

The UHI-DS Tool is implemented using a 3-layer system. The first is a database layer implementing a custom urban information model capable of storing BIM, GIS, local climate, sensor data, and simulation data relevant to UHI mitigation analysis (which will be described in detail in Section 5.2). A browser-based front-end layer provides end users with the ability to visualise and interact with this data. Finally, an application layer provides a core engine and analysis capabilities (i.e. machine learning based climate analysis) which interface the custom urban information model and end user layers.

The UHI-DS Tool was developed as a web application and is publicly available for use. The application utilises the CesiumJS JavaScript framework to implement 3D city visualisation as part of a browser-based front end, with the back end developed in Python using the Flask framework. This is linked to a PostGIS geospatial database which implements the urban information model. An overview of the system architecture is provided in Figure 5. Hosting is provided by the University of New South Wales.

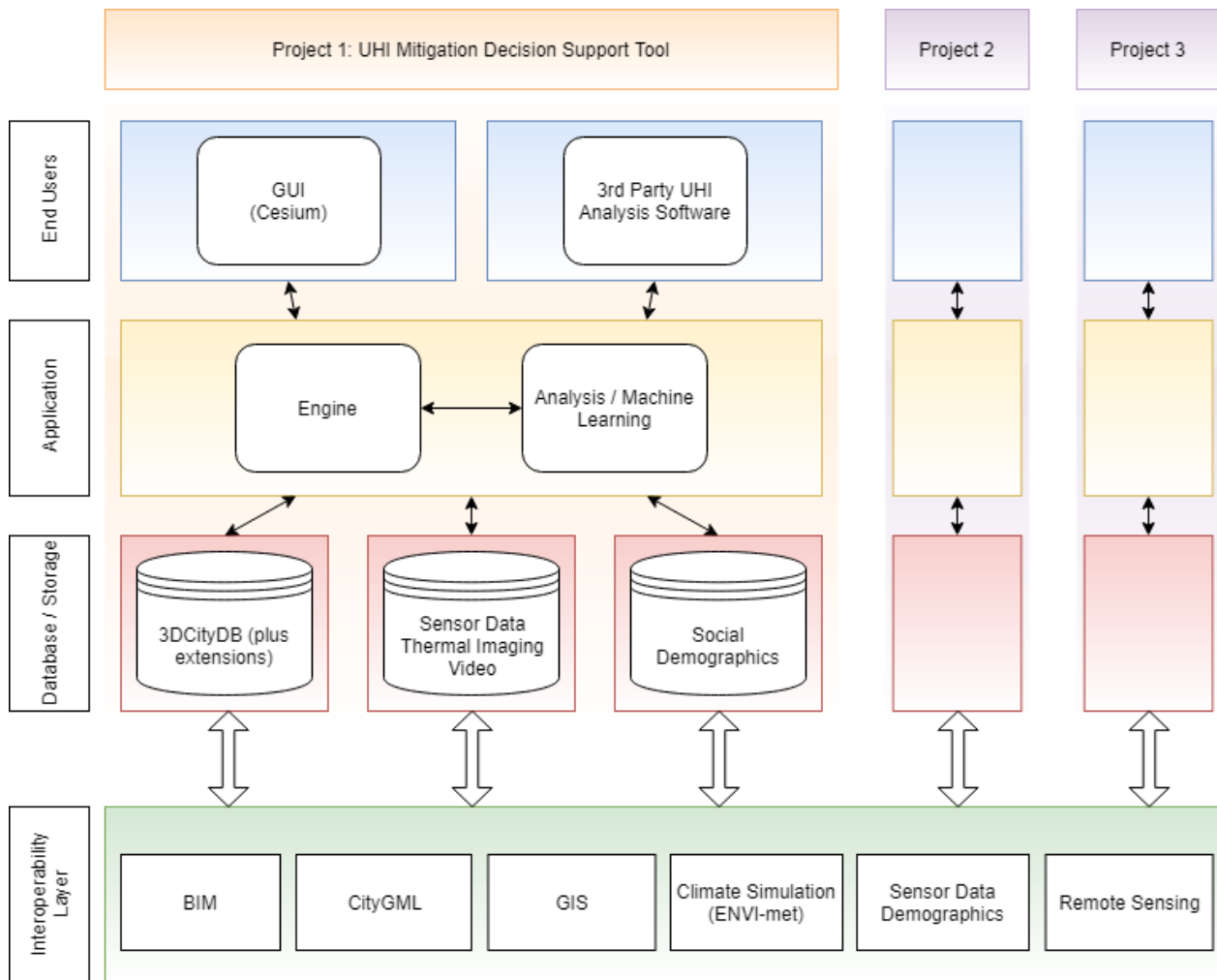


Figure 5: Block diagram for the Urban Heat Island Mitigation Decision Support Tool

5.2 Urban Information Model Integrating Building Information Model (BIM) and GIS

The Urban Information Model integrates Building Information Models (BIM) and Geographic Information Systems (GIS) to provide an integrated smart information environment to support UHI mitigation scenario analysis across both building and precinct scales. In the context of Urban Heat Islands, the Urban Information Model allows for the inclusion of pertinent GIS properties such as land use, street networks, green infrastructure, etc., while also including BIM data including building geometry, facade and roof materials, awnings, etc.

The Urban Information Model was developed based on CityGML (an open standardised data model) and loosely inspired by 3DCityDB implementation. The model has been extended to incorporate city objects and properties required by the UHI mitigation analysis. For example, the model incorporates extensions to object properties including materials such as Solar Reflective Index, temporal object properties such as material application date, land use zoning, as well as additional city objects such as particulate source for modelling evaporative cooling systems. A diagram showing part of city objects in the Urban Information Model is presented in Figure 6.

The establishment of the Urban Information Model allows users to interact with precinct elements at both a precinct and single element scale. Relevant building properties such as roofing and façade materials can be inspected, and changes can be seen in real time as development options are selected and applied. Modelling changes in this way also allows for the easy calculation of useful precinct scale statistics for individual scenarios, including coverage criteria for the Green Star Communities Credit.

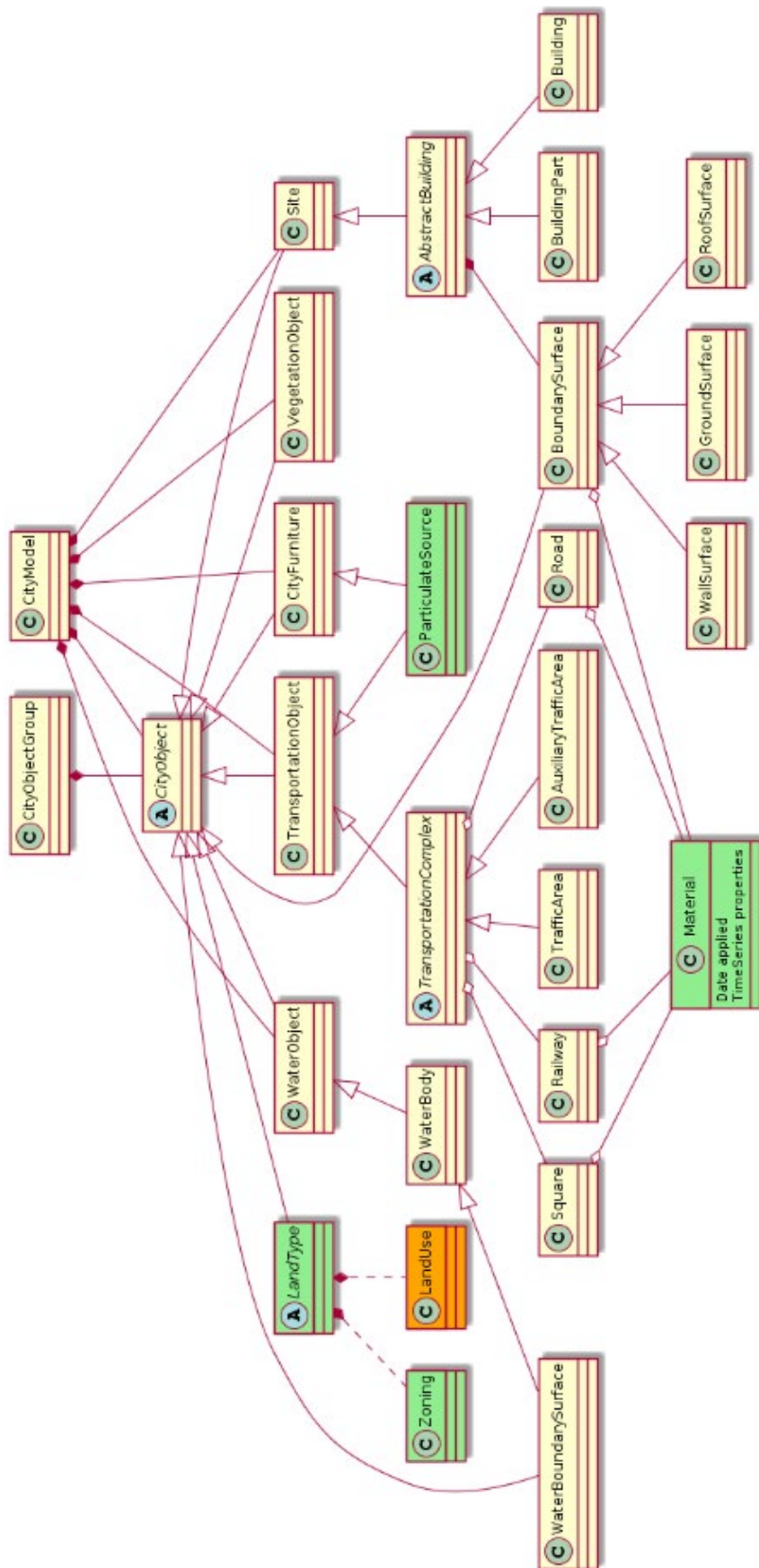


Figure 6: Illustration of part of city objects in the Urban Information Model in the UHI-DS Tool.

5.3 Key Functions of the UHI-DS Tool

The UHI-DS Tool provides 3D visualisation of existing precinct conditions and proposed precinct developments, as well as their impacts on the precinct thermal environment. Furthermore, the tool provides scenario analysis of development alternatives and mitigation options on the 3D visualisation platform, and then views the impact of those scenarios against performance indicators in real-time. Figure 7 provides a screenshot of the user interface of the tool, presenting the scenario analysis of Green Square Town Centre redevelopments and overlay of potential ground cover temperature distribution resulting from the selected mitigation strategies. A list of key functionalities for the UHI-DS Tool are outlined below:

- Examine existing urban context and local climate characteristics of the precinct
By selecting the *Existing* tab users can view precinct characteristics including precinct type, zoning, local climate information and the thermal environment including thermal video and images.
- Undertake scenario analysis of development alternatives and mitigation strategies
Users can select options under *Public Realm*, *Built Form / Buildings* and *Predefined Combination of Scenarios* on the right panel to assess their impacts.
- Visualise the impacts under UHI Mitigation Performance Indicators
User can view the predicted impacts under UHI Mitigation Performance Indicators, including outdoor thermal comfort, average and maximum temperature reduction, air temperature distribution in the precincts.
- Query precinct elements against Green Star Communities Credit Criteria
Users can query the precinct mitigation elements against Green Star Communities Credit Criteria.
- Query precinct object attributes
Users can query the precinct object attributes such as building type, materials, the status of development application, etc.
- Link to UHI Mitigation Index to provide broad guidance to support decision-making



Figure 7: A screenshot of the user interface of the UHI-DS Tool, presenting the proposed Green Square Town Centre redevelopment.

5.4 Input Data and Sources

The input data required for the UHI-DS Tool is outlined in Table 4.

Table 4: Input data and sources

CATEGORY	TYPE	SOURCE / EQUIPMENT
Measured microclimate conditions	Air temperature	Bureau of Meteorology (BOM), Drone with a Thermal Camera, Weather Station (EnergyBus, Ground Measurements)
	Air humidity	
	Surface temperature	
	Wind speed	
	Wind direction	
	Barometric pressure	
	Solar radiation	
	Surface radiation balance	
Current urban conditions and future development plans	Built form	GIS Data, Building Information Models (BIM), CAD Drawings, SketchUp models, 3D models in PDF, Masterplans, Development Applications (DAs)
	• 3D building models	
	• Building roof materials	
	• Building façade materials	
	• Awnings	
	Public realm	
	• 3D city models	
	• Vegetation and trees	
	• Roads	
	• Urban surface materials	
	• Public space	
	• External shading structure	
	• Water body, misting, etc	
	Government planning controls	
• Local environmental plans (LEP)		
Design guidelines by developers	• Design guidelines	Developers

The data requirements for the UHI-DS Tool include spatial data (GIS), development masterplans, and building scale information provided through Building Information Model (BIM), CAD drawings, development applications (DAs) and so on. Local council development control plans (DCP), local environmental plans (LEP) and developers' design guidelines are needed to inform any future development within precincts. Each precinct's development priorities are extracted from these data sources to ensure mitigation scenario options are consistent with future development directions.

On-site microclimate measurements are essential and are drawn from weather stations, ground level measurements and drones. The weather stations record wind speed and direction, air temperature, barometric pressure and dew point. Pyranometers and pyrgeometers are used for ground level measurements to derive net radiation, albedo and sky and surface temperatures. A drone equipped with a thermal camera is used to determine the surface temperatures of different urban fabrics within the precinct.

5.5 Key Outputs and Performance Indicators

Key outputs of the UHI-DS Tool are the assessment outcomes from the mitigation scenarios generated using computational modelling, neural network analysis and scientific assessment models. Computational modelling methods are employed to estimate surface and air temperature distributions in the precinct, which can be validated through on-site

measurements. Scientific assessment models are employed to predict the peak electricity demand during a summer period. A neural network approach is developed to provide scenario analysis of mitigation options for decision-makers.

The assessment results from mitigation scenario analyse fall into four categories: Predicted Surface and Air Temperature Distributions, Outdoor Thermal Comfort Index, Annual Cooling Load Savings and Reduction of Peak Electricity Demand, which are measured through a set of key performance indicators (Table 5). *Predicted Surface and Air Temperature Distributions* can be visualised on the 3D visualisation platform. A comparative analysis between the existing precinct and proposed precinct developments with mitigation options is supported by the UHI-DS Tool. *Outdoor Thermal Comfort* is measured through Universal Thermal Climate Index (UTCI), which is derived from air temperature, humidity, radiation and wind speed of precincts. *Annual Cooling Load Savings* are based on the reduction of annual cooling degree days (CDD), which is influenced by the outdoor air temperature during a year. *Reduction of Peak Electricity Demand* is predicted based on the data from Australian Energy Market Operator and temperature profiles over a summer period using statistical methods (Santamouris, 2017a).

Table 5: Assessment results and key performance indicators from the UHI-DS Tool

ASSESSMENT RESULTS	KEY PERFORMANCE INDICATOR	DESCRIPTION
Surface and Air Temperature Distributions	Air temperature Surface temperature Radiation Humidity Wind speed Wind direction	Street level air temperature Ground cover surface temperature Solar radiation Air humidity Wind speed Wind direction
Outdoor Thermal Comfort Index	Universal Thermal Climate Index (UTCI)	The air temperature of the reference environment, which produces an equivalent dynamic physiological response according to a human thermoregulation model (Brode, P, et al., 2011). Factors that influence UTCI are air temperature, humidity, radiation and wind speed.
Annual Cooling Load Savings	Reduction of Annual Cooling Degree Days (CDD)	CDD is a measurement to quantify the demand for energy needed to cool a building in a particular location over a year.
Reduction of Peak Electricity Demand	Peak demand during the summer period	It refers to the electricity power required in a certain period that is significantly higher than average supply levels. A key factor that influences peak electricity demand is the temperature profiles throughout this period.

6 Case Study: Green Square Town Centre Redevelopment

This section introduces the Green Square Town Centre case study, including precinct characteristics, local climate conditions, development alternatives and key findings including the effectiveness of mitigation strategies.

6.1 Outline and Rationale

Green Square is one of Sydney’s many inner-city redevelopment areas. From 2011 to 2016 the Green Square area has almost doubled in population density and the number of days above 38°C has risen to 4 in 2016 (Bodilis et al., 2017). This poses increased heat stress risk for its inhabitants. The Microclimate and Urban Heat Island Mitigation Decision-Support Tool (UHI-DS Tool) has been applied to the Green Square Town Centre (GSTC) redevelopment to assist City of Sydney Council and developers to effectively mitigate these extreme heat conditions. To support City of Sydney’s aspiration for a world-class resilient community in the heart of Sydney, the UHI-DS Tool provides decision-support for assessing the urban heat implications of development proposals. The objective is to enable decision makers to determine what the most effective urban design interventions are in reducing air temperature in the GSTC redevelopment precinct during extreme heat conditions.

6.2 Microclimate Characteristics

As part of an initial study towards identifying the existing microclimate characteristics for Green Square, fieldwork was conducted in early with temperature, wind speed, and humidity data collected on site using the UNSW Energy Bus. Thermal imagery was also collected via drone (an example is shown in Figure 8). Hotspots include unshaded hardscape such as roads, as well as some roofs.

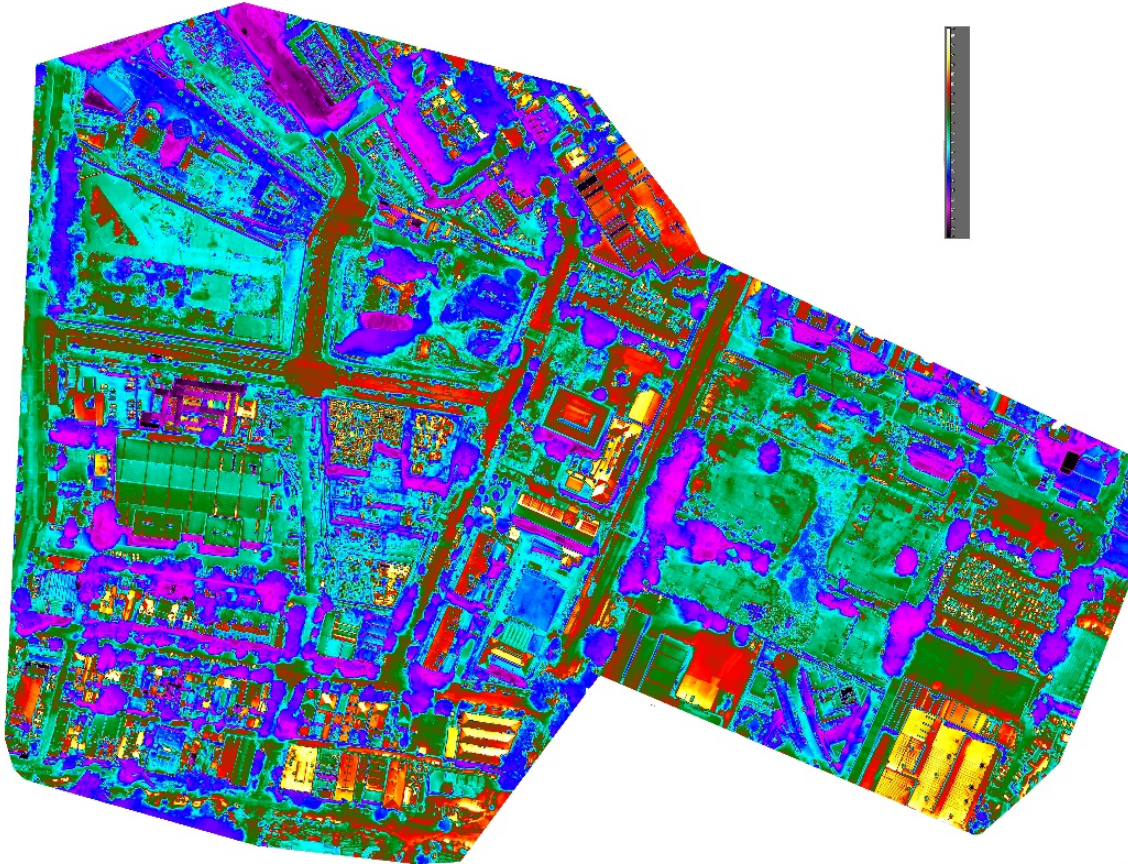


Figure 8: Urban heat characteristics of GSTC precinct

6.3 Development Characteristics

GSTC is an inner-city redevelopment area of Sydney that is being transformed from an industrial precinct into a thriving residential community. The planned Town Centre is a 14ha urban renewal project within the larger redevelopment of Green Square (278 ha), which is expected to provide over 30,000 new residential dwellings by 2030. The Town Centre is currently under development and upon completion it will house a wide range of residential, mixed-use and community facilities, including a new aquatic centre and library.

6.4 Outputs, Findings, and Implications

The UHI-DS tool is a performance-based decision-support platform which enables users to quickly and easily trial alternative mitigation measures to assess their impact in real-time. Initial results from applying the UHI-DS Tool to the GSTC redevelopment show the impact of the proposed redevelopment and the potential of alternative design interventions and mitigation strategies to reduce air temperature in the precinct during extreme heat conditions.



Figure 9: Future GSTC development plans (Landcom, 2017)

The scenario analysis was conducted for GSTC using the heat wave conditions experienced in Sydney over the summer of 2017-2018 as the microclimate context (using the air temperature at 2 pm on a heat wave day in February 2018). The results of the mitigation potential of several planning scenarios for GSTC are presented in Figure 10 and Table 6.

- **Proposed GSTC Redevelopment**

Comprised of planned buildings, new street networks and public open spaces.

Analysis Outcome: Hot spots were identified through modelling as being the Library Plaza (38°C), as well as the Drying Green (37.5°C) and open area to the east of the Aquatic Centre (36°C). These were likely due to the relative lack of outdoor shade and tree canopy cover.

- **A Plan of Trees and Vegetation**

Planned tree canopy cover of the GSTC redevelopment which includes street tree planting along new street networks and in the new public parks (City of Sydney, 2018).

Analysis Outcome: GSTC Precinct reduction in average air temperature of 0.6°C, and maximum reduction in local air temperature of 2.4°C.

- **Compliance with Green Star Communities Urban Heat Island Credit Requirements**

Increased cool pavements, roads and roofs to meet minimum Green Star Communities Urban Heat Island Credit requirements (Green Building Council of Australia, 2016).

Analysis Outcome: GSTC Precinct reduction in average air temperature of 0.7°C, and maximum reduction in local air temperature of 2.5°C. Cool pavements and roads were effective at reducing air temperature.

- **Combination of Mitigation Options**

Cool and green roofs on most buildings where feasible, cool surfaces for pavements and roads, water evaporative systems such as misting cooling systems in the Library Plaza area and a plan for a small water body.

Analysis Outcome: GSTC Precinct reduction in average air temperature of 1.3°C, and maximum reduction in local air temperature of 6°C by water evaporative systems. The large reduction in local air temperature is due to the localised impact of the water evaporative systems in the Library Plaza area.

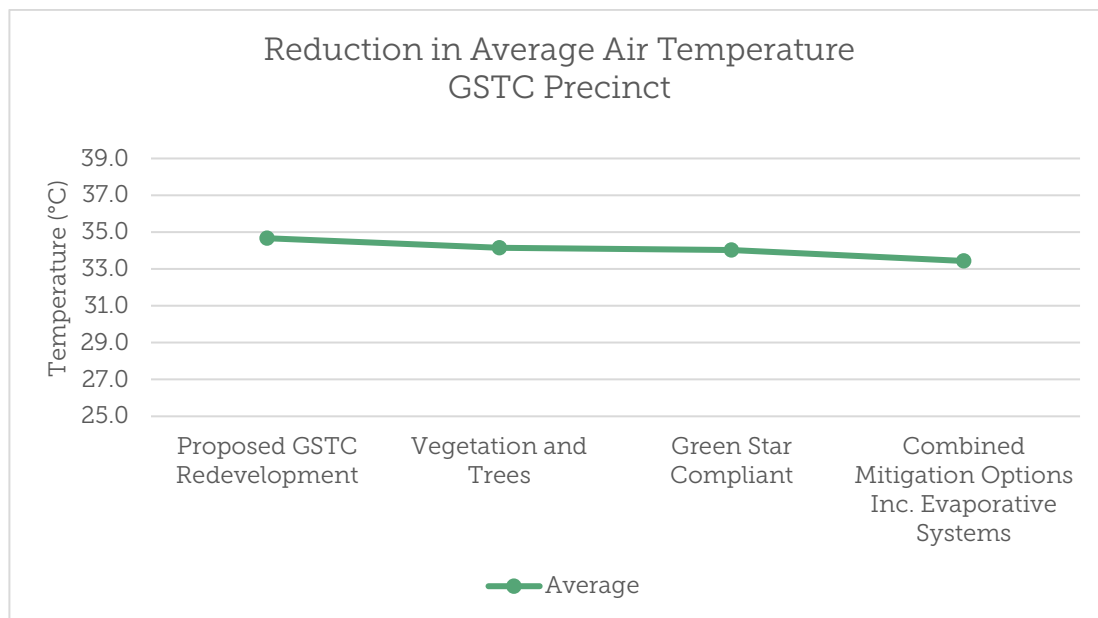


Figure 10: Estimated reduction in average air temperature in GSTC Precinct

The urban heat scenario analysis of GSTC using the UHI-DS Tool can identify 'hot spots' in the precinct and examine the effectiveness of current and alternative planning decisions to mitigate extreme heat conditions.

Due to the limitation for urban greenery within GSTC, alternative mitigation strategies are required to effectively reduce air temperature and to meet Green Star Communities requirements. Analysis results from the UHI-DS tool suggest that alternative mitigation strategies for GSTC can be focused on the large open spaces within the public realm and combined mitigation options including cool pavements, evaporative systems, etc. Water evaporative systems are a highly effective strategy to reduce localised air temperature in those areas.

The benefit of the UHI-DS tool is that it allows users to explore these different mitigation strategies in a specific urban development context and see their localised and precinct-wide impact in real-time (Figure 11). The UHI-DS Tool therefore offers an effective means of scenario-based planning and decision-making for governments, developers and planners seeking to reduce urban heat within their precincts.

Table 6: Estimated maximum reduction in local air temperature

MITIGATION OPTIONS FOR GSTC	MAXIMUM REDUCTION IN LOCAL AIR TEMPERATURE
Vegetation and Trees	2.4°C
Green Star Compliant	2.5°C
Combination of Mitigation Options Including Water Evaporative Systems	6°C

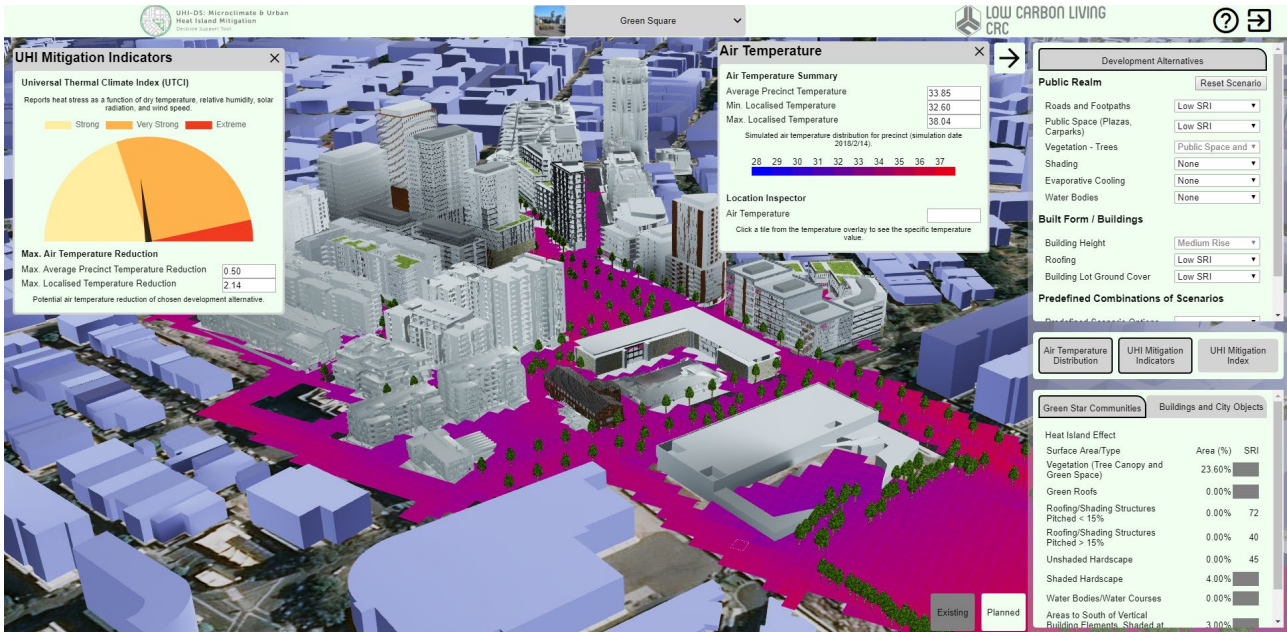


Figure 11: Example of part of planned buildings in GSTC and overlay of potential ground cover surface temperature distribution from the UHI-DS Tool

7 Case Study: Parramatta Civic Link Redevelopment

This section introduces the Parramatta Civic Link case study, including precinct characteristics, local climate conditions, development alternatives and key findings including the effectiveness of mitigation strategies.

7.1 Outline and Rationale

The Parramatta Civic Link redevelopment aims to provide a green, pedestrianised zone linking the Parramatta Square and Parramatta river. The project is located in the heart of the Parramatta CBD, and therefore shares the key characteristics of CBD redevelopments. However, Parramatta is a suburb of Western Sydney (as opposed to the relatively coastal Green Square); an area which is known to be relatively susceptible to the Urban Heat Island effect.

7.2 Microclimate Characteristics

As part of an initial study towards identifying the local climate characteristics for Parramatta, thermal imagery was collected via drone (an example is shown in Figure 12). Hotspots include hard surfaces and building facades.

7.3 Development Characteristics

The Parramatta Civic Link project is a CBD redevelopment bounded by Parramatta river to the North, Parramatta train station to the South, Marsden St to the West, Smith St to the East. It contains both business and mixed-use zoning and is expected to support a residential population of 34,600 by 2036 (with a corresponding working population of 83,000). Two proposed pedestrian zones will also be developed in the Civic Link and Church St.

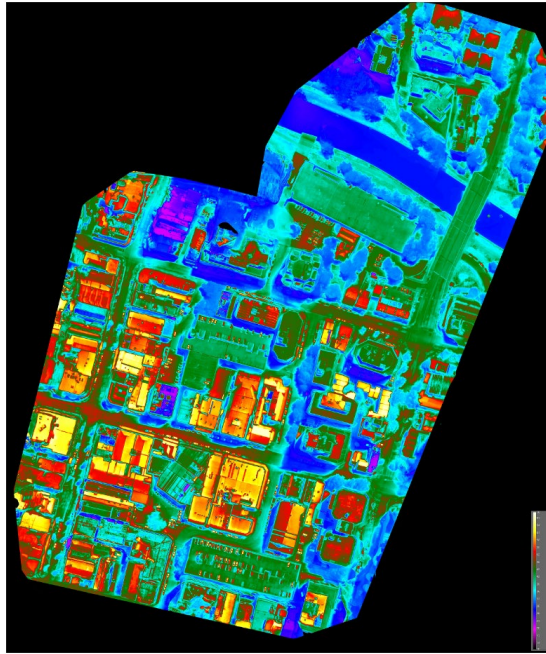


Figure 12: Urban heat characteristics of Parramatta precinct

7.4 Outputs, Findings, and Implications

The scenario analysis was conducted for Parramatta Civic Link using the heat wave conditions experienced in Sydney over the summer of 2017-2018 as the microclimate context (using the air temperature at 2 pm on a heat wave day in February 2018). The results of the mitigation potential of several planning scenarios for Parramatta Civic Link are presented in below.

- **Proposed Parramatta Redevelopment**

Comprises planned buildings, the new civic link pedestrian area, and public open spaces. Buildings for which detailed plans were not available were modelled based on development and planning control.

Analysis Outcome: Hot spots were identified through modelling as being open, unshaded hardscape such as Centenary Square (37°C).

- **A Plan of Street Trees**

This scenario involved placing street trees along the Parramatta Civic Link and in areas of Centenary Square.

Analysis Outcome: Modelling identified a precinct wide average temperature reduction of 0.07°C with a maximum local temperature reduction of 1.4°C.

- **Cool Roads, Pavements, and Hardscape**

This scenario involved applying high SRI treatments to roads and pavements in the CBD area, as well as hard surfaces in Centenary Square.

Analysis Outcome: Modelling identified a precinct wide average temperature reduction of 0.5°C with a maximum local temperature reduction of 2.4°C.

- **Combination of Mitigation Options**

Cool and green roofs on low buildings where feasible, cool surfaces for plazas, roads, and pavements, water evaporative systems such as misting cooling systems in Centenary Square and the Civic Link, street trees along the Civic Link, and shading structures.

Analysis Outcome: Modelling identified a precinct wide average temperature reduction of 0.9°C with a maximum local temperature reduction of 6.8°C.

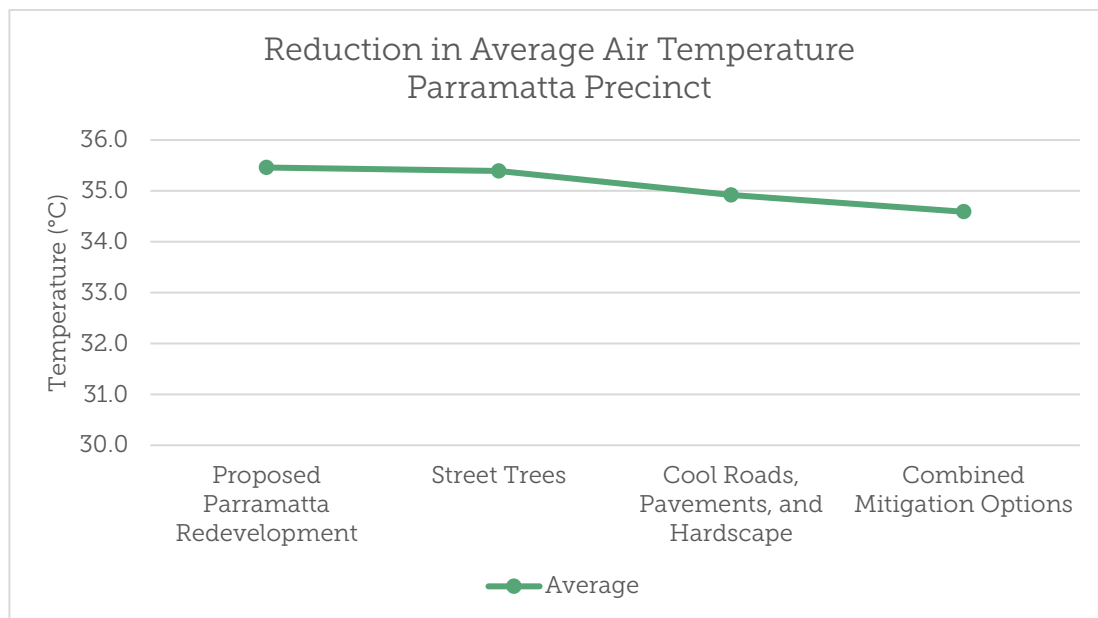


Figure 13: Estimated reduction in average air temperature in Parramatta Civic Link Precinct

The Parramatta Civic Link is a CBD redevelopment which brings with it many constraints on the type and location of mitigation options that may be applied. Although street level temperatures in some places were partially mitigated by shading provided by buildings, open areas saw large improvements with the addition of vegetation and outdoor shading structures. Widespread application of cool surfaces was also effective. As with the Green Square Town Centre redevelopment, the addition of evaporative cooling systems proved highly effective, and can produce significant local air temperature reductions for unshaded hot areas such as Centenary Square.

Table 7: Estimated maximum reduction in local air temperature

MITIGATION OPTIONS FOR PARRAMATTA	MAXIMUM REDUCTION IN LOCAL AIR TEMPERATURE
Street Trees	1.4°C
Cool Roads, Pavements, and Hardscape	2.4°C
Combination of Mitigation Options Including Water Evaporative Systems	6.8°C



Figure 14: Example of part of planned buildings in Parramatta Civic Link and overlay of potential ground cover surface temperature distribution from the UHI-DS Tool

8 Case Study: Macarthur Heights Greenfield Development

This section introduces the Macarthur Heights case study, including unique precinct characteristics, local climate conditions, development alternatives and key findings including the effectiveness of mitigation strategies.

8.1 Outline and Rationale

Macarthur Heights is a greenfield residential development by Landcom near Campbelltown in South Western Sydney. Western Sydney is particularly susceptible to the Urban Heat Island effect, with UHI intensities as high as 7–10 K having previously been recorded. In contrast to the high density Green Square and Parramatta Civic Link case studies, the different local climate and development characteristics present distinct challenges in mitigating urban overheating.

8.2 Microclimate Characteristics

As part of an initial study towards identifying the local climate characteristics for Macarthur Heights, fieldwork was conducted in early with temperature, wind speed, and humidity data collected on site using the UNSW Energy Bus. Thermal imagery was also collected via drone (an example is shown in Figure 15). Hotspots are primarily dark roofs, although unshaded hardscape such as roads are also included.

8.3 Development Characteristics

The project is a 122ha medium density zoning area in the Campbelltown City Council area. It will contain 966 homes and is situated between Australian Botanic Garden to the west and Macarthur train station and shopping centre to the east. The Macarthur Heights development is being conducted in 5 stages, with all stages scheduled for completion in 2019. Our case study analysed the performance of mitigation options when applied to the stage 5 development at the south of the precinct.

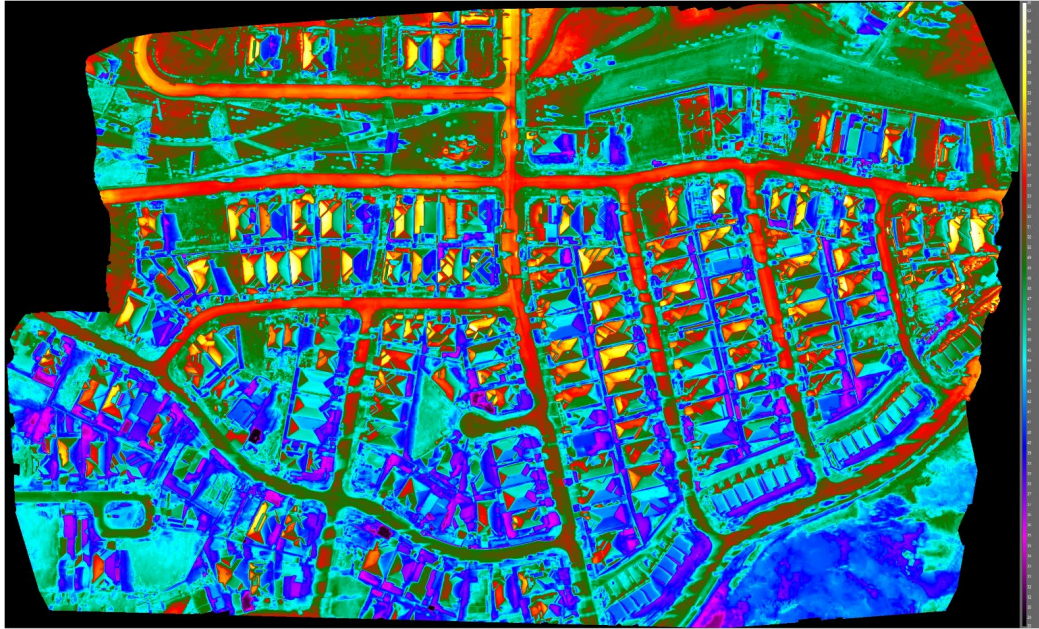


Figure 15: Urban heat characteristics of Macarthur Heights precinct

8.4 Outputs, Findings, and Implications

The scenario analysis was conducted for Macarthur Heights using the heat wave conditions experienced in Sydney over the summer of 2017-2018 as the microclimate context (using the air temperature at 2 pm on a heat wave day in February 2018). The results of the mitigation potential of several planning scenarios for Macarthur Heights development are presented in below.

- **Proposed Macarthur Heights Redevelopment**
 Comprises planned buildings, terrain, and road networks (modelled based on planning documents for the Macarthur Heights development).
Analysis Outcome: Hot spots were identified through modelling as those in lower, sheltered areas, as well as streets with orientations perpendicular to incoming wind flow (33°C).
- **A Plan of Street Trees**
 This scenario comprised the addition of street trees for the entire Macarthur Heights road network.
Analysis Outcome: Negligible impact on ground level temperatures were observed, with extremely minor increases in local temperature (0.05°C) observed in several places. This is likely due to the assumed terrain and wind flow characteristics (see below for more detail).
- **A Plan of Cool Roofs**
 This scenario comprised the extensive application of cool roofs.
Analysis Outcome: Modelling identified a precinct wide average temperature reduction of 0.12°C with a maximum local temperature reduction of 0.32°C.
- **Combination of Mitigation Options**
 This scenario comprised the extensive application of cool roofs, in addition to cool road surfaces, street trees, and a small lake to the north of the precinct.
Analysis Outcome: Modelling identified a precinct wide average temperature reduction of 0.25°C with a maximum local temperature reduction of 0.85°C.

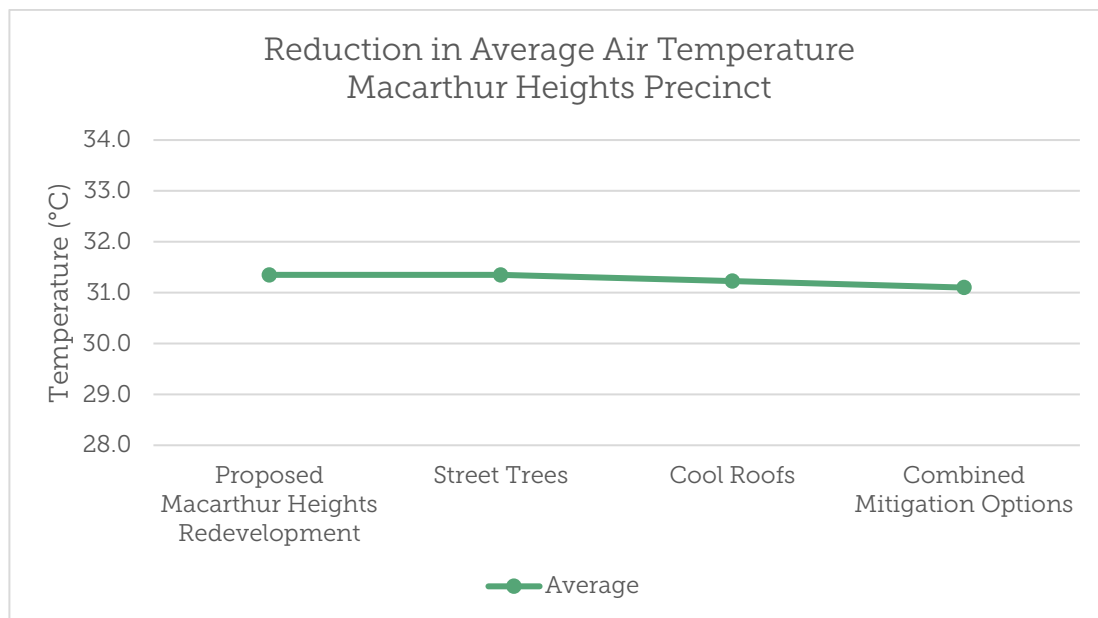


Figure 16: Estimated reduction in average air temperature in Macarthur Heights

Widespread application of cool surfaces (roads and roofs) were observed to provide the greatest effect among tested options in simulations for Macarthur Heights.

A key characteristic of the Macarthur Heights precinct was the direction of wind flow, street orientation and compact single dwelling typology. When conditions including a westerly wind were simulated, streets running perpendicular to the wind flow observed slightly increased temperatures relative to other streets. Terrain also played a crucial role; the simulated terrain was highest in the west of the model, with the precinct on the far side of the hill under a westerly wind. This can possibly explain the low impact of street trees in the simulations; the addition of trees smoothed the simulated westerly air flow over the top of the model reducing turbulence (and therefore ground level air speed). It is key to note these simulations do not support the conclusion that street vegetation should not be applied in Macarthur Heights, but rather care should be taken in selecting options that will perform under a certain precinct context. The effectiveness of mitigation options was influenced by winds and precinct typology in the Macarthur Heights precinct.

Table 8: Estimated maximum reduction in local air temperature

MITIGATION OPTIONS FOR MACARTHUR HEIGHTS	MAXIMUM REDUCTION IN LOCAL TEMPRATURE
Street Trees	-0.05°C
Cool Roofs	0.32°C
Combination of Mitigation Options	0.85°C



Figure 17: Example of part of planned dwellings in Macarthur Heights and overlay of potential ground cover surface temperature distribution from the UHI-DS Tool

9 Urban Heat Island Mitigation Index

9.1 Overview

The Urban Heat Mitigation Performance Index aims to provide local governments with a broad range of urban heat island mitigation options tailored to certain microclimates and urban contexts. The Mitigation Index forms a practical outcome of research taxonomising urban contexts for use analysing the effectiveness of different urban heat island mitigation strategies.

The Urban Heat Island Mitigation Index can run in standalone mode or be accessed through the UHI-DS Tool.

9.2 Scope

The purpose of the Urban Heat Island Mitigation Performance Index is to provide general advice to inform decision-making, while the Urban Heat Island Decision-Support Tool (detailed in the previous sections) is designed to provide advice based on specific precinct characteristics.

9.3 UHI Mitigation Index Structure

The Index allows users to rate 17 different mitigation options in the context of the chosen objective, climate region and urban context. Instead of providing a quantitative assessment result, mitigation options are presented based on their expected suitability for the selected conditions; it is possible that multiple, equally applicable solutions may exist. The Index also communicates the potential effectiveness of different mitigation options, both individually and in selected, important combinations, built on literatures and case studies.

The Index allows users to seek information for up to four objectives: outdoor thermal comfort, health risks, energy demand, and water demand (Figure 18). Mitigation options in line with these objectives are further identified based on the microclimate characteristics of a major Australian city (defined according to the NatHERS climate zones), and specific urban context. Urban contexts are based on the most commonly recognised land-zoning and urban typologies found across Australia. Mitigation options are grouped into three categories: building, public realm and community.

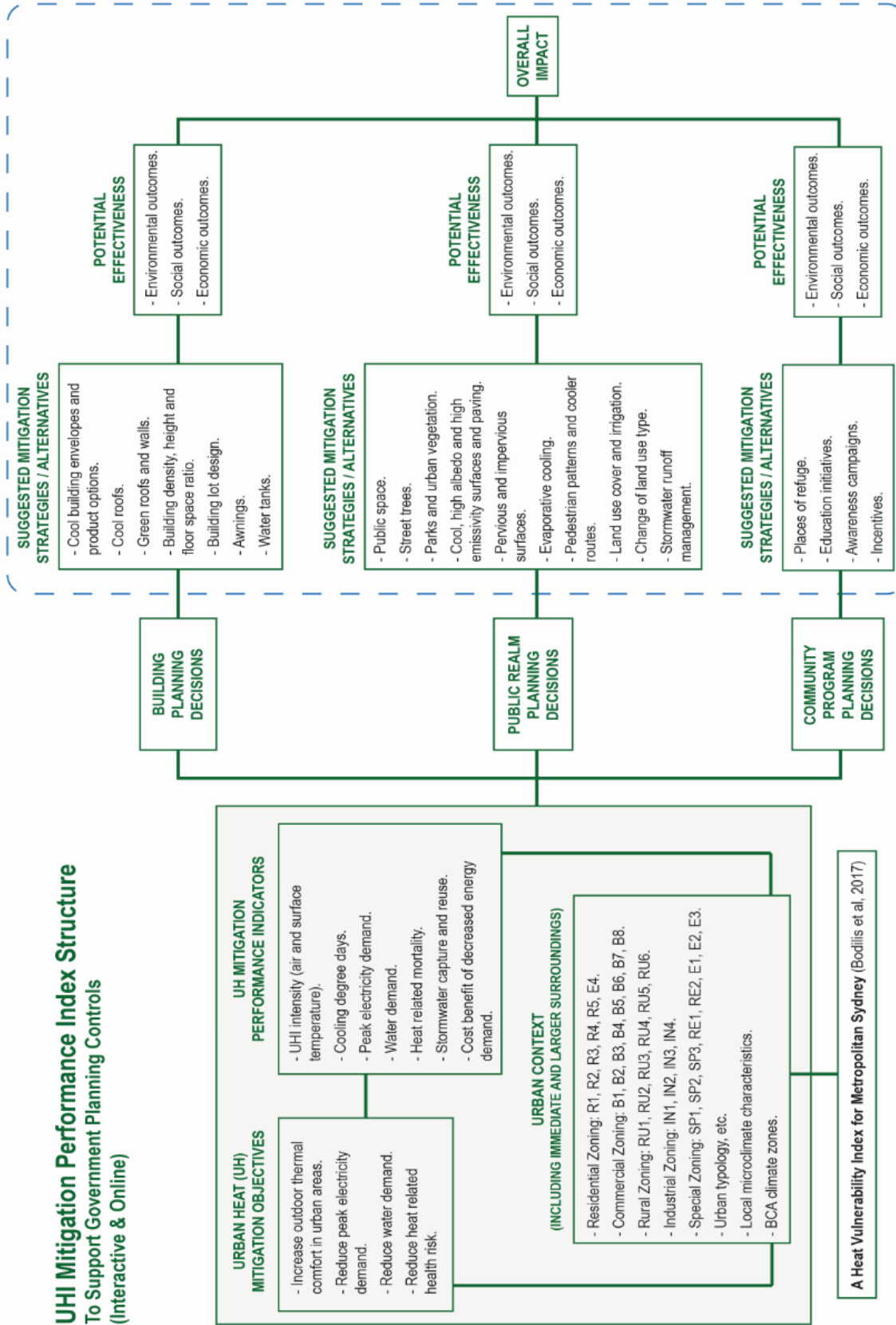


Figure 18: UHI Mitigation Performance Index Structure

9.4 Multi-Criteria Assessment of Mitigation Options

The Index was developed using the multi-criteria assessment method (Figure 19). For each of the 17 mitigation options we scored the effectiveness for each individual objective, climate region, and urban context on a scale from -1 (negative impact) to 3 (highly effective). A final rating indicating the expected suitability for each mitigation option was then computed as a sum of their scores (normalised and weighted using the multi-criteria assessment method).

9.5 Online Interactive User Interface of the Index

The user interface for the UHI Mitigation Performance index (online) is designed to be as intuitive as possible. Objectives, climate regions, and urban contexts are selected in the navigation bar, after which mitigation strategies are listed with a colour coding indicating their suitability. Individual strategies can then be selected to display explanatory information with links to relevant CRCLCL research and other literature sources.

An overview of the primary user interface (example shown in Figure 20) is as follows:

1. Users select a climate region and urban context from the menu on the left. One or more objectives are also selected.
2. Mitigation options are scored according to their suitability for the chosen condition, and a list of suitable options is given in the top left section.
3. Users can select to include or exclude mitigation options in building, public realm, or community.
4. Users can select a specific mitigation option from the list to see provisions and effectiveness displayed in the bottom and right sections.
5. The combinations tab can be selected from the top menu to see potential effectiveness of combinations of multiple mitigation options.
6. The Index provides a link to the Human Vulnerability Index for Metropolitan Sydney developed via another project.

10 Conclusions

This report outlines the research objectives, framework, methods and key findings from case studies of the project, in addition to the major project outcomes below:

Microclimate and Urban Heat Island Mitigation Decision-Support Tool (Online)

<http://uhimitigationindex.be.unsw.edu.au/uhitool/login.html>

Access is restricted. Login credentials can be requested from UHI-Index@unsw.edu.au

A short video is available at <https://youtu.be/rcd7VYveu14>

Urban Heat Island Mitigation Index (Online)

<http://uhimitigationindex.be.unsw.edu.au/>

Entire tool is publicly available.

To date the tool has been demonstrated at multiple CRCLCL expos and has been (or is currently being) evaluated by project partners and government and industry users, including City of Sydney, Parramatta City Council, Adelaide City Council, Greater Sydney Commission, OEH, Landcom, BlueScope Steel, Melbourne Water, Blacktown City Council, VIC Department of Environment, Land, Water and Planning, City of West Torrens, SA, Western Australian Local Government Association and so on.

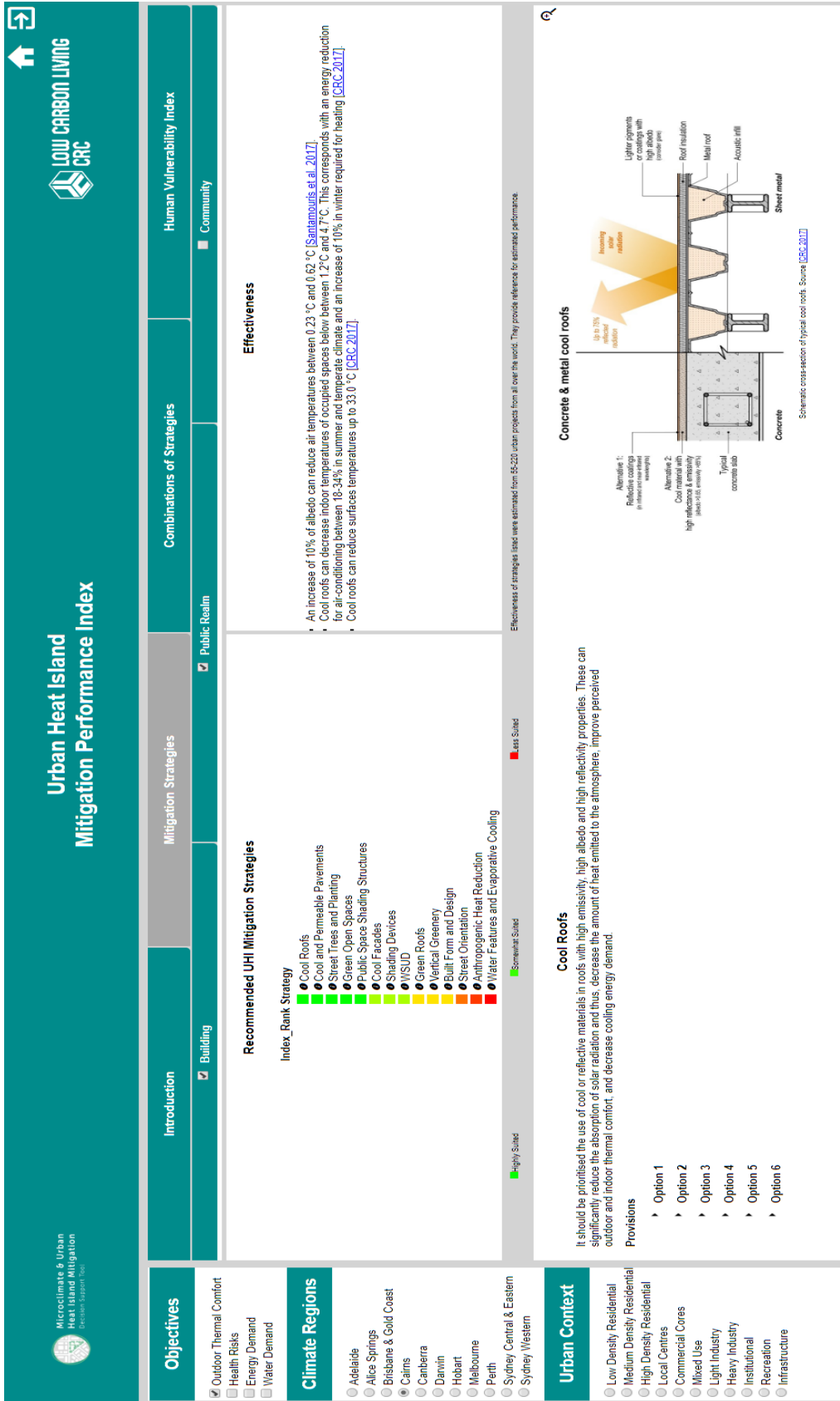


Figure 20: The Interactive User Interface of the UHI Mitigation Index

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APPENDIX: UHI-DS Tool User Guide

Web Browser

Google Chrome is the recommended browser for the UHI-DS Tool. Do not use Internet Explorer. Other browsers may work but are unsupported at this time.

Computer Requirement

The UHI-DS Tool is recommended to be accessed via a relatively modern computer machine with a dedicated graphics card. An old computer machine may cause error messages.

Login

STEP 1: Select a precinct from the list.

STEP 2: Input username and password (contact UHI-Index@unsw.edu.au for access).

STEP 3: Click login button to progress to the selected precinct. If an incorrect username or password is used, the page will reload.

Instruction: Click to open an instruction document.

Main User Interface

The main user interface displays the 3D precinct and buildings which are existing, under implementation and/or planned. Movement can be accomplished by:

Move camera	Click left mouse button and drag
Rotate camera	Click middle mouse button and drag
Zoom camera	Use middle mouse button



1. Existing or Planned Precinct View

Switch between the *Existing* and *Planned* precinct view. *Existing* view shows the existing site, microclimate characteristics and links to thermal video/imagery captured via drone. *Planned* view provides urban heat mitigation scenario analysis for development alternatives.

A message and spinner will be shown here while the page is loading. This may take a few minutes depending on the quality of the internet connection and computer being used.

2. Development Alternatives

Development Alternatives panel provides options for *Public Realm* and *Built Form/Buildings* to explore. *Predefined Combinations of Scenarios* are also provided for urban heat mitigation analysis.

Click the *Reset to Basecase* button to undo changes to development alternatives.

3. Urban Heat Mitigation Indicators

The results of mitigation of urban overheating are measured through key performance indicators, which include Air Temperature Distribution, Universal Thermal Climate Index (UTCI), Max Air Temperature Reduction (including the average and localised). Other indicators will be provided over time.

Click a tile from the temperature overlay to see the specific temperature value.

4. Green Star Communities Information

Click *Green Star Communities* to query information of the percentage of building or landscaping elements that reduce the impact of heat island effects in the total project site area.

5. Building and City Object Information

Click *Building and City Objects* to query information of a selected building or city object. The information includes building name, type, address, roof materials, façade materials, etc.

6. UHI Mitigation Index

Click *UHI Mitigation Index* to access the separate UHI Mitigation Index page which will provide broad guidelines on mitigation strategies for selected objectives, climate regions and urban context.

7. Precinct Selector

Switch to a separate precinct.

8. Logout

Logout and return to the login screen.

Troubleshooting

- It is possible to move the 3D view such that the camera becomes stuck inside a building or zoomed out too far to relocate the precinct. In such cases reloading the page (press F5) will move the camera back to the precinct.
- On rare occasions it is possible that accessing the Login page will produce a message *500 Internal Server Error*. On such an occasion reloading the page should remove the error and allow one to access the tool.