



WESTERN SYDNEY
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MICROCLIMATES OF BROOKVALE

TAKING THE PULSE OF THE NORTHERN
BEACHES INDUSTRIAL HEARTLAND

APRIL 2025

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We pay our respect to the Garigal and Guringai people, the traditional custodians of the land on which this work has taken place. We acknowledge the lasting trauma that the assumption of terra nullius has inflicted on all Aboriginal and Torres Strait Islanders, past and present. We hope our work contained in this document demonstrates that we do care for people and country.

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SUMMARY

The suburb of Brookvale in Sydney's east is the industrial centre of the Northern Beaches Local Government Area (LGA). The area is gaining increased recognition for its growing micro-brewery industry, emerging arts scene, and innovative small businesses. Also, the local population is growing rapidly. The proximity of Brookvale to the Pacific Ocean means that summer temperatures are relatively mild compared to those experienced further west in the Sydney Basin. However, summer air temperatures can rise above 40°C, which presents health risks for local communities. Low canopy cover across the industrial part of Brookvale means little shade and transpiration cooling is provided when it is needed the most.

Future development across the precinct will be informed by the Brookvale Structure Plan, which outlines priorities for the next 15 years starting in 2023. Development decisions on where and how issues related to urban heat should be addressed requires a sound understanding of the microclimatic variation across the suburb. This report provides such knowledge. It is the most detailed analysis of urban microclimates across the precinct to date. Near-surface air temperatures (3 m above ground) were recorded at 30 locations including streets dominated by commercial or residential buildings and car parks. More than 300,000 individual measurements were collected in the summer of 2024/25 (1 December 2024 to 15 February 2025).

Dale Street was one of the hot spots identified in Brookvale, with the highest mean air temperature of 23.9°C, almost 1.5°C warmer than the coolest spot on Clearview Place. Warmer locations were in the south and south-eastern part of Brookvale, where compact industrial spaces dominate, and tree canopies are sparse and very small. In contrast, the cooler locations were in the very north-western part of the precinct, just to the east of the extensive vegetation within Allenby Park, and where tree canopy cover was higher even within the built environment. The highest temperature recorded on Mitchell Road close to the wide and heavily traffic area of Pittwater Road where $T_{\max}$ was almost 5°C hotter than on Ada Avenue, which had the lowest $T_{\max}$. These differences highlight that large intra-urban variation in temperatures across the small spatial scales within Brookvale, and the importance of green and grey infrastructure in driving thermal patterns. The role of open and vegetated space was also significant in allowing the sea breezes to provide cooling along east-

west oriented streets. Road and street corridors running in an east-west direction were cooled by sea breezes when areas to the east were dominated by green space, but no such cooling was measured when the area of the east was dominated by grey infrastructure. The sea breeze had also an overall thermal effect across the suburb, cooling the eastern part of the suburb more than the west.

The large dataset provides a benchmark of intra-urban heat before the implementation of cooling interventions outlined in the Brookvale Structure Plan. Results can be used to quantify improvements in thermal conditions, providing a starting point for evidence-based heat mitigation. Based on the findings of this study, the following points should be considered when making decisions to help improve microclimates across Brookvale.

- For street trees and shade plantings, select tree species that will develop large, dense canopies to provide daytime shade and air temperature reductions.
- Capitalise on the cooling effect observed along streets with an east-west orientation to facilitate air movement and maximise cooling from the sea breeze when it occurs.
- Increase tree canopy cover and other means of air cooling (e.g., engineered shade) in selected streets where locations were detected with the highest daily mean maximum air temperatures including at the roundabout at the Warringah Mall.
- Continue to measure and monitor urban air temperatures and urban heat island effects across Brookvale during and after the implementation of the Brookvale Structure Plan to demonstrate the efficiency of mitigation actions.



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GLOSSARY

- **blue infrastructure** – water infrastructure that includes ponds, lakes, rivers, creeks and stormwater resources
- **BoM (Bureau of Meteorology)** – executive agency of the Australian Government responsible for providing weather services to Australia and surrounding areas
- **extreme heat day** – day when daily absolute maximum air temperature reached $\geq 40^{\circ}\text{C}$
- **green infrastructure** – living or vegetated infrastructure including both natural and designed areas on public and private land, such as gardens, parks, street trees, green roofs, green walls and laneways
- **hot day** – day when daily absolute maximum air temperature reached $\geq 35^{\circ}\text{C}$
- **IPCC (Intergovernmental Panel on Climate Change)** – a United Nations body for assessing the science related to climate change, and responsible for providing regular reports of findings and options for adaptation and mitigation
- **LGA (local government area)** – legally designated (third tier of government in Australia) parts of a state or territory for which incorporated local governing bodies have responsibility
- **NBC (Northern Beaches Council)** – the governing body of the local government area in north-eastern Sydney
- **SEED (The Central Resource for Sharing and Enabling Environmental Data in NSW)** – a NSW Government portal providing a central place for community and government can access, interrogate, contribute, and share the state's environmental data
- **T_{air}** – near-surface air temperature ($^{\circ}\text{C}$)
- **T_{daytime}** – mean air temperature calculated for the 8 hours between 10:00 hours and 18:00 hours
- **T_{max}** – daily maximum air temperature, typically recorded in the afternoon ($^{\circ}\text{C}$)
- **T_{mean}** – average summer air temperature ($^{\circ}\text{C}$)
- **T_{min}** – daily minimum air temperature, typically recorded in the morning ($^{\circ}\text{C}$)
- **$T_{\text{nighttime}}$** – mean air temperature calculated for 8 hours from 21:00 on one day to 05:00 hours the next day
- **UHIE (urban heat island effect)** – a phenomenon whereby urbanised areas are warmer than nearly rural areas
- **UHIE_a (air urban heat island effect)** – urban heat island effect measured in air temperatures
- **UHIE_s (surface urban heat island effect)** – urban heat island effect measured in surface temperatures
- **warm night** – night when daily absolute minimum air temperature reached $\geq 20^{\circ}\text{C}$
- **ΔT (temperature differential)** – the difference between two air temperature values ($^{\circ}\text{C}$)

1. BACKGROUND



FIGURE 1. Location of the suburb of Brookvale in relation to the Sydney Central Business District (CBD), NSW (lower inset) and Australia (upper inset).

1.1. PROJECT RATIONALE

Summers in Greater Sydney are getting hotter. Growing evidence highlights the problems of increasing heat in the western suburbs, but urban heat is also impacting the suburbs and communities in Sydney's east. Hotter summers negatively impact people, communities, the natural environment, and economies. An increasing number of people living in eastern Sydney are subjected to thermally challenging, and potentially dangerous living conditions today and the tendency is towards more

extreme heat in the near future (Pfautsch et al., 2025). Benchmarking heat in Sydney's local government areas (LGAs) provides an important, evidence-based starting point for the development of strategies and policies that aim at reducing the impacts of heat.

Brookvale is a suburb of north-eastern Sydney (Fig. 1), located 16 km north-east of the central business district (CBD). It lies in the centre of the local government area of the Northern

Beaches Council, Brookvale is a key strategic centre within the Northern Beaches and is known for its significant industrial contributions that cover almost 40% of the suburb. In 2023, it was home to around 3,600 residents. The area has recently gained recognition for its growing micro-brewery industry, emerging arts scene, and innovative small businesses. The precinct is well-connected to the Sydney CBD via a major road network and bus services.

Brookvale suffers from urban overheating due to its dominant industrial character and low tree canopy cover. The precinct is undergoing significant changes, with future development shaped by the Brookvale Structure Plan (NBC, 2023a). The plan outlines priorities for the next 15 years starting in 2023, including construction of more than 1,350 new homes and creation of 900 jobs. Other highlights include a 5,000 m² town square/greenspace and improvements to streetscapes, notably by “Green Links” which are expected to lead to improved pedestrian and bike connectivity throughout the precinct.

The Structure Plan sets out key changes across the precinct that include the broadscale improvement of human thermal comfort through increased blue and green infrastructure. To quantify the improvement in thermal conditions that result from actions outlined in the Plan, a sound understanding of current microclimatic conditions across Brookvale is needed. The Bureau of Meteorology does not operate an official weather station anywhere in the Northern Beaches Council LGA. Therefore, site-specific information of microclimatic variation across Brookvale is not available. The resulting lack of knowledge about the variation in air temperature represents a serious limitation for the development and implementation of effective urban cooling interventions during the Brookvale renewal process.

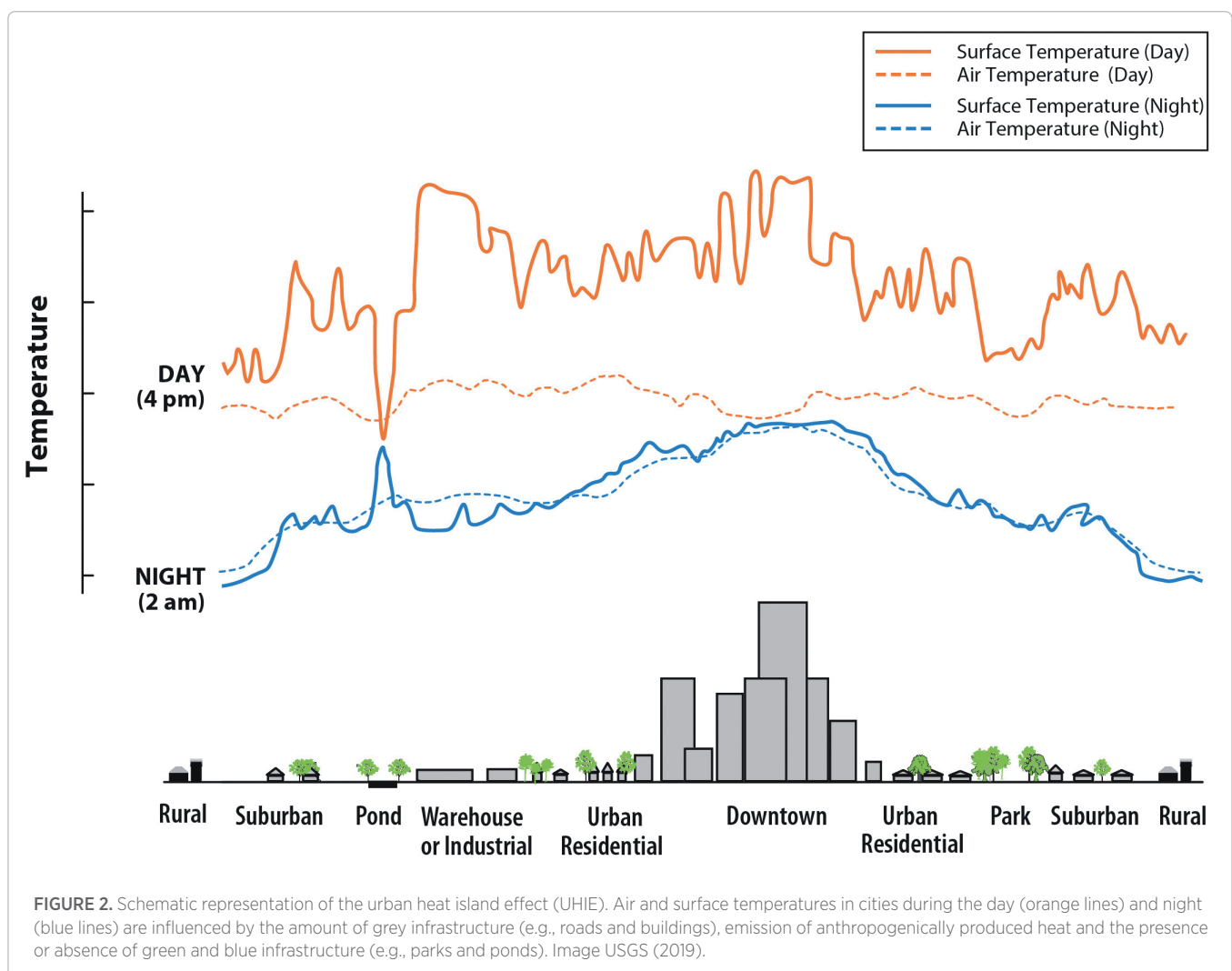
The work presented here will provide highly detailed, empirical evidence about the variability of microclimates across Brookvale by identifying hot and cool zones and associated hyper-local heat island effects, establishing mean, day- and night-time air temperature differences for a range of urban typologies, and analysing the thermal performance of the anticipated new public plaza of the precinct.

1.2. URBAN OVERHEATING AND URBAN DESIGN

Urban overheating is a growing problem that has been documented in more than 13,000 cities around the world (Tuholske et al., 2021). Urban overheating is the result of compounding effects from broadscale warming of the atmosphere (i.e., climate change) and local effects of absorption, reflection and reemission of incoming solar radiation (i.e., heat island effects) (Nazarian et al., 2024). Traditional approaches to urban development involve removal of open green space and vegetation through construction of buildings, roads and other hard infrastructure. This alters the landscape energy balance and leads to the development of a phenomenon known as the urban heat island effect (UHIE), whereby urban areas are notably warmer than nearby rural areas (Deilami et al., 2018).

The heating effect from land use change is compounded by a subsequent rise in anthropogenically-produced heat and movement of traffic within the urbanised area (Yun et al., 2020; Husni et al., 2022). The magnitude of the UHIE is therefore influenced by the extent of development both in terms of its density and spatial spread.

Urban heat island effects can be detected in air and surface temperatures and can be observed during both the day and the night. During the day, changes in surface temperatures are large and highly variable, depending on surface material types and solar radiation loads. In comparison, daytime air temperatures are affected to a lesser extent by surface properties and display less variability across the built environment (Fig. 2). At night, both air and surface temperatures are notably increased in urban compared to non-urban areas as hard surfaces such as concrete, bricks and asphalt re-radiate long-wave radiation absorbed during the day back into the surrounding air (Kaluvarachichi et al., 2020). Synoptic weather patterns, geographic location, topography, elevation, and distance from the coast can further amplify the air UHIE (Yun et al., 2020).



Urban design and construction influence the magnitude of the UHIE. Referred to collectively as ‘bioclimatic design strategies’, these measures can address urban overheating and enhance building environmental performance. Bioclimatic design strategies include a focus on passive design principles and urban morphology such as natural ventilation and solar orientation (Bera et al., 2024). Urban morphology impacts air flow patterns within

a city and can be used to assist in addressing heat islands effects in heavily built-up areas. The density, height, and spatial orientation of buildings can influence airflow and the movement of heat. Higher building density results in greater heat accumulation and lower wind velocities (Kubota et al., 2008), while wider streets orientated to facilitate local cooling air flows can also reduce UHIE (Karimomoshaver et al., 2021).

Bioclimatic design strategies encompass climate-responsive solutions to urban heat (Bera et al., 2024). A key solution is the provision of shade. Summer shade can significantly reduce ground surface temperatures by up to 15°C in Germany (Rahman et al., 2021) and 19°C in the UK (Amson et al., 2012). Temperatures of standardised reference surfaces (black and white tiles and artificial grass) in the shade

were reduced by as much as 45°C compared to those in the full sun in Sydney, Australia (Sharmin et al., 2022). Air temperature above shaded surfaces is also reduced substantially. A reduction of around 3°C was reported in India (Kumar et al., 2023), and reductions of 5-7°C were measured in the UK (Amson et al., 2012). In Sydney, shade reduced mean and maximum air temperatures by 1.1 °C and 3.7 °C, respectively (Sharmin et al., 2022).

Additional design principles that are used to reduce urban heat include the use of reflective surfaces, especially for roads and pavements. The amount of heat absorbed by a surface depends on its thermal characteristics and properties of materials used. Darker colours have lower albedo and absorb more solar radiation, whereas lighter coloured surfaces have higher albedo and absorb less solar radiation (Qin and Hiller, 2014). Even when unshaded, changes to surface albedo can reduce surface temperatures of altered asphalt by up to 15°C compared to conventional asphalt (Cheela et al., 2021). Altering surface evaporation by replacing natural soil and vegetation with non-evaporating materials has decreased the latent heat flux and increased ambient temperatures in cities. Similarly, the reverse process can be used to reduce urban heat (Vujovic et al., 2021).

Anthropogenic heat production and emissions exacerbate air temperature increases in cities and are especially pronounced in areas of high traffic (Wu and Zhang, 2021) and during times when the use of air conditioners is high (Shahmohamadi et al., 2011). Heat emissions from factories can also lead to significant warming in industrialised areas (Abounaga et al., 2024). Such effects are currently unknown for the area of Brookvale.

1.3. HEAT AND HUMAN HEALTH OUTCOMES

Exposure to hot air temperatures is a crucial factor in the development of heat illnesses and heat stress. The long-term, chronic effects of rising air temperatures due to a warming climate are a growing health concern for the human population (IPCC, 2022). Increased urban heat is associated with higher rates of mortality and morbidity from both short-term extreme heat (Wu et al., 2022) and heatwaves (Paredes-Fortuny et al., 2024). Globally, excessive heat causes more deaths than any other type of dangerous weather (WHO, 2024). In 2023, increased heat exposure put people engaged in outdoor physical activities at a risk of heat stress for 27.7% more hours, and 6% more hours of sleep were lost than in 1986-2005 (Romanello et al., 2024). In Australia, high nighttime temperatures in particular have become a major contributor to heat stress (Commonwealth of Australia, 2024).

Climate change scenarios for metropolitan Sydney project that by 2090, average temperatures will increase by around 1.2°C under a low emissions scenario and around 3.4°C under a high emissions scenario (NSW Government, 2025). Actions already undertaken by government, communities, households and businesses will help adapt to the impacts of a warmer climate and create a more sustainable, productive and equitable future. However, local councils need to continue to work to improve heat mitigation and protect both the environment and the human population from the hazards of urban overheating.

1.4. CLIMATE, URBAN HEAT AND THE ROLE OF GREEN INFRASTRUCTURE IN BROOKVALE

The climate in Brookvale is warm and temperate, with moderately hot, humid summers and cooler, dry winters. The warmest period tends to be January, when average temperatures fluctuate between a high of 26.2°C and a low of 20.3°C. Throughout the year, in Brookvale, there are 152.6 rainfall days, providing an average of 635 mm of precipitation. The eastern section of the suburb is about 1.7 km from the coast, with the open green spaces of Curl Curl Lagoon and John Fisher Reserve that progress westwards towards areas dominated by industrial development. There is also the large, forested area of Allenby Park in the western part of the suburb. To the south, Brookvale is connected to green fairways of the Warringah and Manly Golf Clubs that can channel cool air from a southerly direction into the suburb.

Within the Northern Beaches Council, Brookvale is a priority area for intervention and tree canopy improvements. The area is listed as vulnerable due to factors including lower tree canopy cover than most other suburbs in the LGA (mean cover of 21%, Fig. 3). Tree canopy is between 0 and 20% in the southern and eastern parts of the suburb where the majority of the heavily built-up industrial spaces are located. In these areas, and especially in the eastern part of the Brookvale precinct the surface urban heat island effect is up to 11°C (Fig. 4).

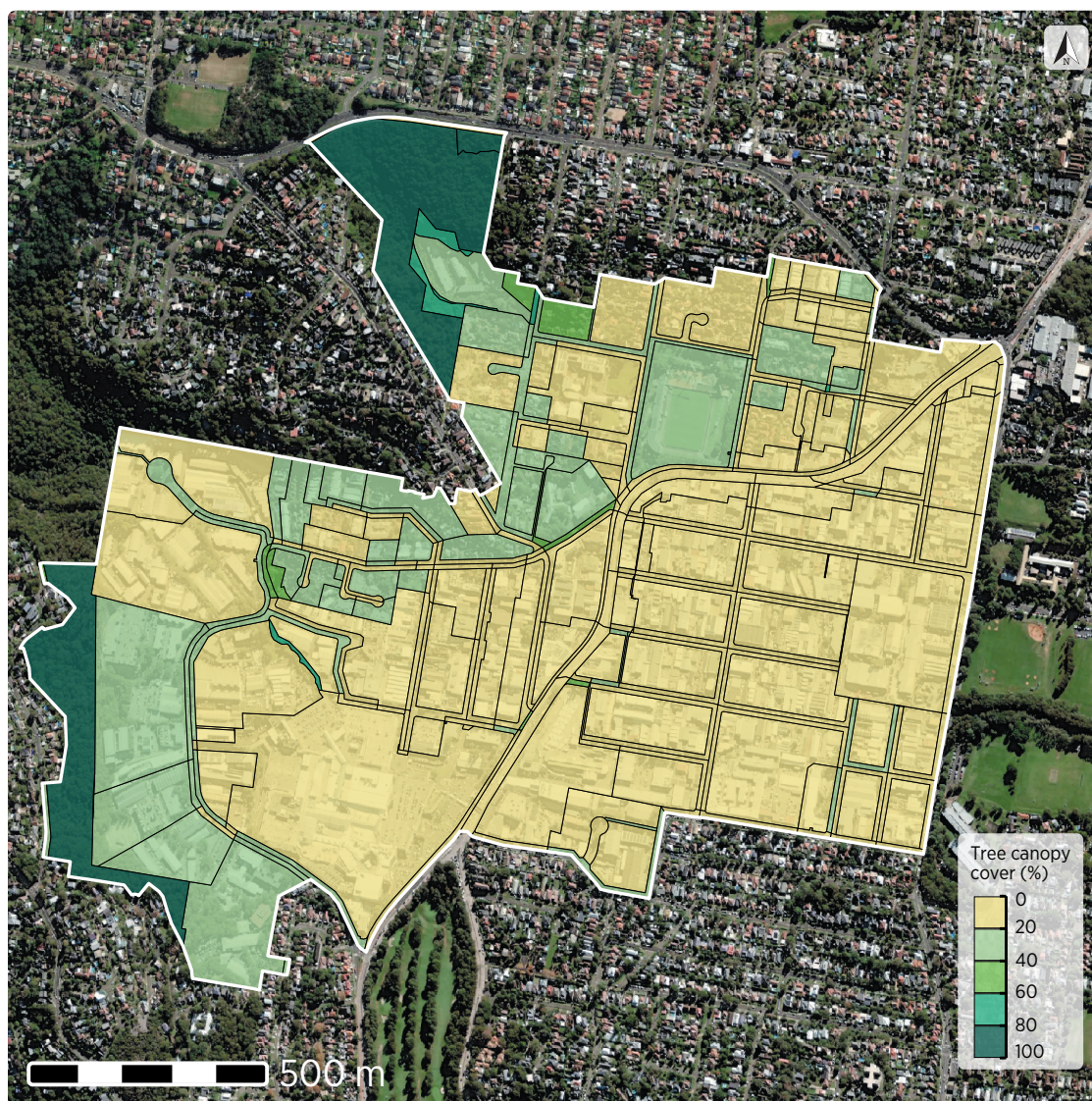


FIGURE 3. Tree canopy cover (%) for all vegetation >3 m tall across Brookvale showing most areas have very low cover, sitting in the 0-20% band. Data was sourced from the Central Resource for Sharing and Enabling Environmental Data in NSW (SEED) for 2022. The white solid line indicates the boundary of the suburb (Australian Bureau of Statistics, 2021). The background is satellite map from ©mapbox.

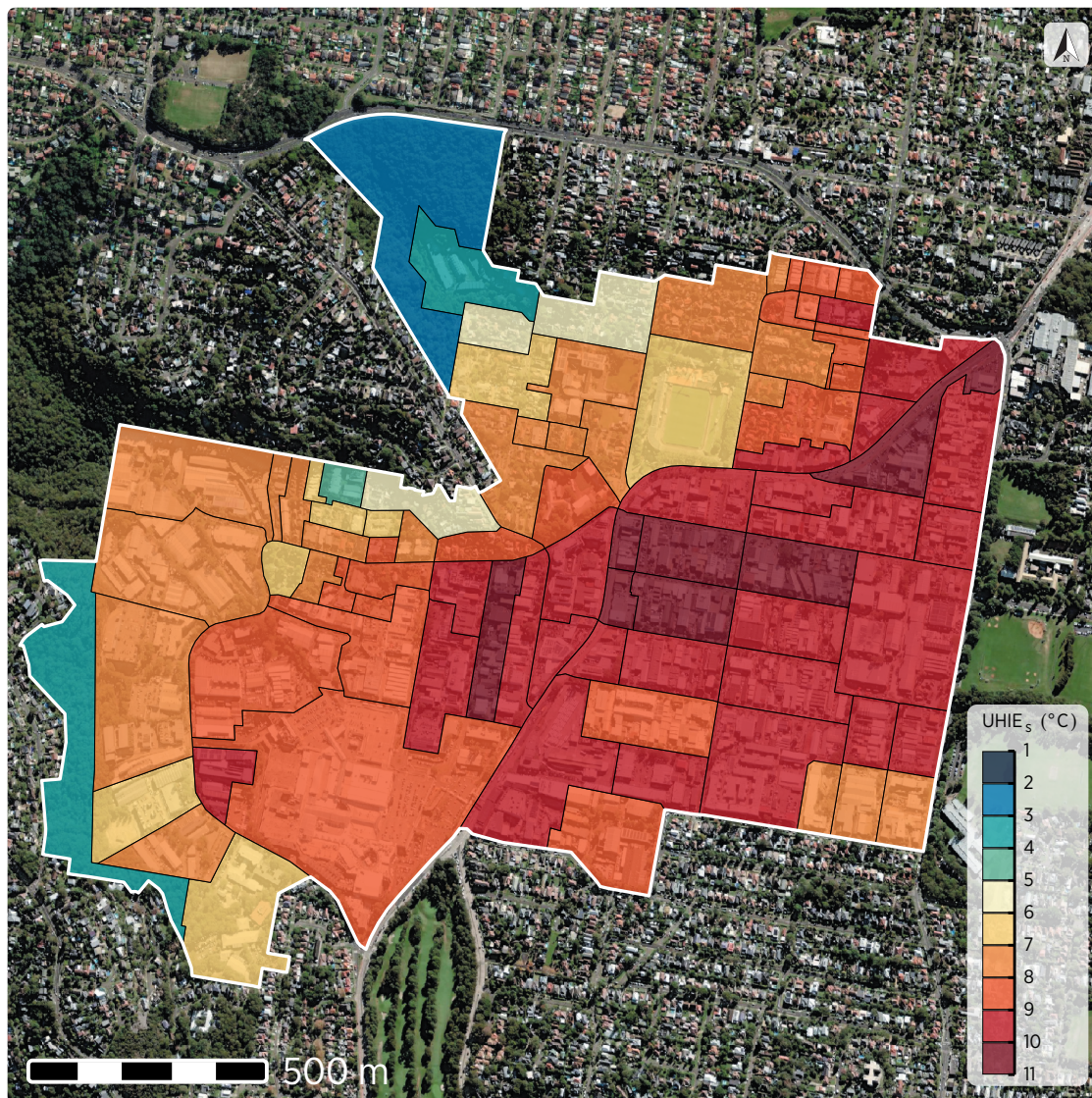


FIGURE 4. Surface urban heat island effect (UHIE_s, °C) across Brookvale. The map shows the variation in land surface temperature calculated using a non-urban vegetated area as reference. Data was sourced from the Central Resource for Sharing and Enabling Environmental Data in NSW (SEED) and designed for the summer of 2015/2016. The white solid line indicates the boundary of the suburb (Australian Bureau of Statistics, 2021). The background is a satellite map from ©mapbox.

1.5. THE BROOKVALE STRUCTURE PLAN

The Brookvale Structure Plan (BSP) was endorsed by the Northern Beaches Council in November 2023. It outlines the direction of future land use and growth for the 15 years from the time of its endorsement. It sets the vision and land use strategy for Brookvale that aims to reinforce its role as a strategic centre, taking into account environmental, social, economic, traffic, transport and accessibility considerations.

Historical development of Brookvale has also delivered limited greening and low tree canopy cover levels, which has resulted in a low-amenity environment that suffers from urban heat and has limited areas for recreation and leisure. The BSP presents the opportunity to renew and improve the amenity of Brookvale through high quality design of new buildings

and public facilities. This can be achieved by encouraging amenity-focused, mixed-use development that enables valuable urban renewal outcomes including new open spaces, new pedestrian connections and laneways, and enhanced urban greening and tree canopy cover. The inclusion of more blue and green infrastructure can also reduce flood risk and urban heat, while filtering rain runoff, providing wildlife habitat and improving air quality.

In addressing urban overheating, the BSP identified future 'Green Links' - which are local streets where tree canopy improvements are slated (green dotted lines in Fig. 5) - including Roger Street, Cross Street/Clearview Place, Winbourne Road, Orchard Road, Short Street, Mitchell Road, Ada Avenue, and Miles Street. The works will complement the Northern Beaches

Council's Urban Tree Canopy Plan, which promotes protection of trees to provide habitat, shade, wind protection and aesthetic qualities while affording economic, environmental, social and health benefits (NBC, 2023b).

The BSP also has a focus on the urban centre around the Warringah Mall and nearby B-line bus stop (Pittwater Road) where strategic planning of the new town square and community facilities are to be located (Fig. 5).

Addressing the many challenges and maximising opportunities to deliver positive outcomes is complex and will require planning interventions and significant investment. It will also demand innovative thinking and identification of the right balance between productivity, liveability, and sustainability outcomes.



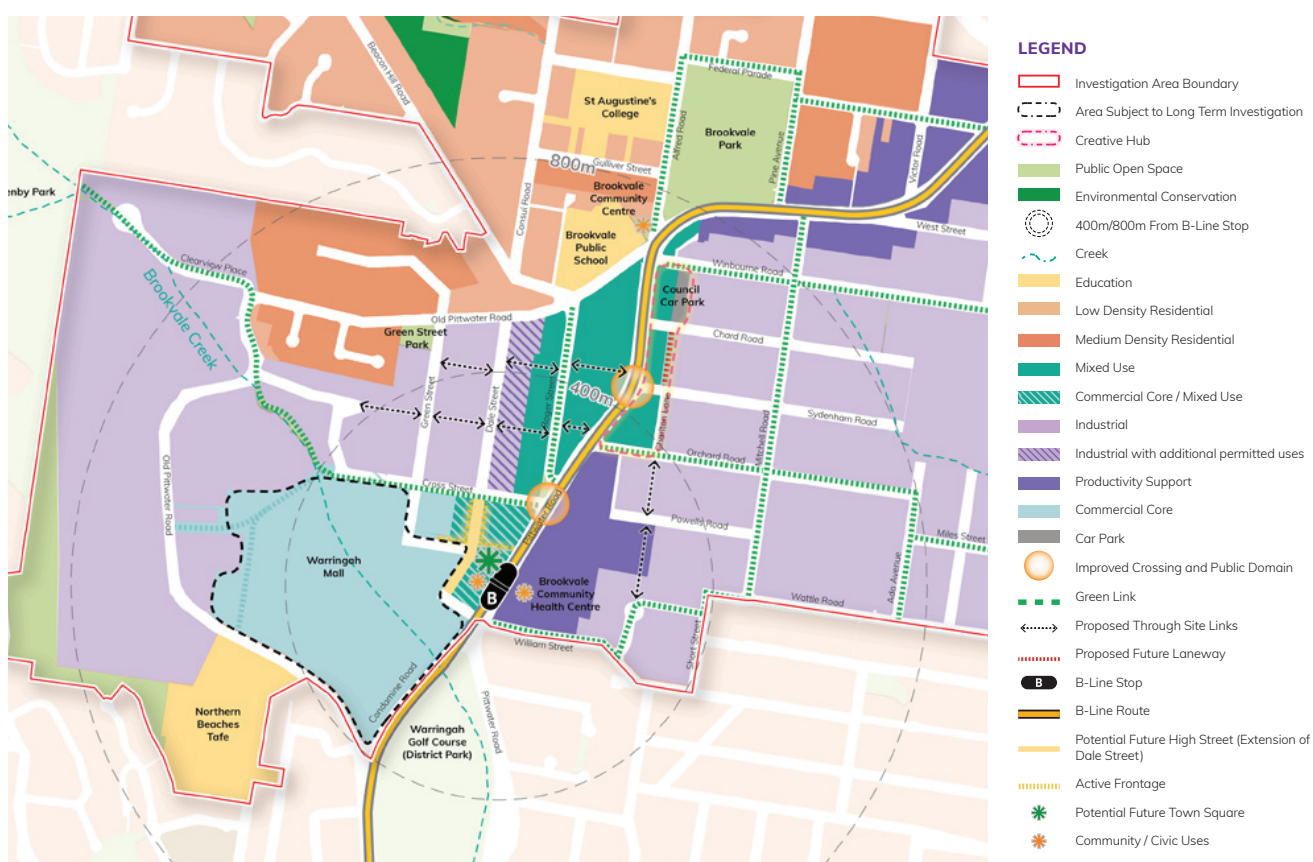


FIGURE 5. Map showing aspects of the Brookvale Structure Plan including those of interest in this study: the 'green links' marked as green dotted lines, and the Warringah Mall area in cyan and outlined with a black dashed line. (Source: NBC, 2023a).

2. PROJECT AIMS

The aim of this work was to characterise the microclimates of Brookvale during summer, using empirical measurements of near-surface air temperatures. This report presents the findings from the collection of field data, providing a thermal benchmark for the area by

- identifying relative hot and cool zones and related urban heat island effects,
- defining thermal patterns in built environments, and
- establishing mean, day- and nighttime air temperature differences for a range of urban typologies.

The project was designed using two major streams. Stream 1 focussed on benchmarking microclimate variations through heat mapping, including along the future green links detailed in the Brookvale Structure Plan. Stream 2 investigated the microclimate of the anticipated public plaza around the car parks of Warringah Mall in the south of the precinct. The results are interpreted to inform the development of effective cooling interventions and support strategic heat adaptation and mitigation planning.



3. METHODOLOGY

3.1. MICROCLIMATE LOGGERS

Near-surface air temperature (T_{air}) was recorded with custom-made microclimate loggers designed and manufactured at Western Sydney University (WSU). Each logger consisted of a water-resistant, single-use temperature sensor (Tempmate S1 V2, Imtec Messtechnik, Heilbronn, Germany; Fig. 6A) and a reflective weather shield to protect the sensor from direct solar radiation (Fig. 6B). The sensor's accuracy was 0.5°C, and temperatures were recorded at 0.1°C increments. Each sensor was programmed to measure air temperature at 10-min intervals. The shield was made of aluminium which has low thermal mass and was coated with a high-reflective enamel white paint to reduce the risk of heat absorption. The bottom of the shield was open, and three holes were cut into the top to enable passive ventilation of the interior (Fig. 6C). Loggers have been calibrated against other commercially available air temperature sensors, as well as official temperature data from the BoM, and results have been published previously (see Pfautsch et al., 2023). Briefly, air temperature measurements from loggers deployed in North Parramatta and Sydney Olympic Park were closely related to measurements taken from nearby official weather stations ($R^2 > 0.95$ with the exception of minimum temperatures where $R^2 > 0.80$), and air



FIGURE 6. Components of the custom-made microclimate loggers used in this report: (A) water-resistant, single-use temperature sensor (Tempmate S1 V2), (B) protective shield with mounted logger inside, (C) shields with punched holes at the top, and (D) example of logger installation on tree branch.

temperatures recorded from loggers installed in trees were not significantly different from those recorded on street light posts, indicating that values from the loggers can be reliably used for intra-urban microclimate studies.

Loggers were installed on the lower branches of trees 3 m above the ground on residential and industrial streets and car parks. Figure 7

shows examples of mounting locations in industrial and residential streets. Each location where a logger was installed was carefully geo-tagged and documented visually. This information was recorded to repeat measurements in the future where loggers can be installed at identical locations.



FIGURE 7. Examples of loggers installed on trees across Brookvale: (A) Dale Street, (B) Winbourne Road, (C) Short Street, and (D) Ada Avenue. (Photo credit: S. Pfautsch).



3.2. MEASUREMENTS AND ANALYSIS

Microclimate loggers were deployed in 30 locations across the suburb on 28 November 2024, and they continuously recorded T_{air} data until 16 February 2025 when they were collected (Table A1 in Appendix). The data collected between 1 December 2024 and 15 February 2025 were used for the analysis,

resulting in a total of 332,640 individual T_{air} measurements. The loggers were split into Stream 1 and Stream 2. Figure 8 shows the locations of the loggers used in both Streams, while location details are provided in Table A1 at the end of this report.

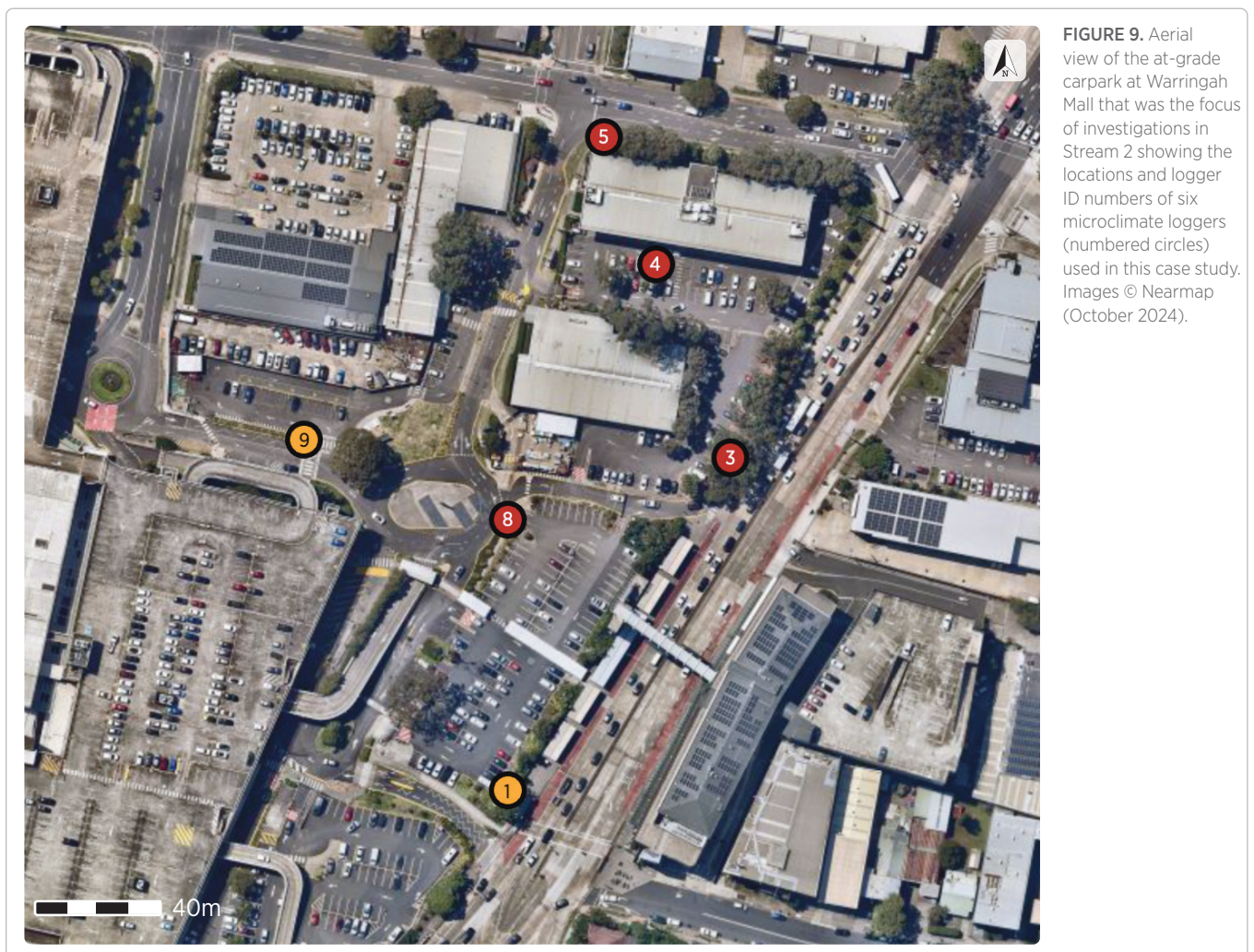


FIGURE 9. Aerial view of the at-grade carpark at Warringah Mall that was the focus of investigations in Stream 2 showing the locations and logger ID numbers of six microclimate loggers (numbered circles) used in this case study. Images © Nearmap (October 2024).

Stream 1 used 26 loggers (shown as numbered cyan and orange symbols in Fig. 8) for heat mapping across the industrialised part of the suburb. The residential area in the north of the suburb was not part of this project. This dataset contained 288,288 individual T_{air} measurements. Stream 2 focused on a specific

area within the suburb, which was at-grade car park at Warringah Mall and nearby bus stop of the B Line (Pittwater Road). The Stream 2 used data recorded in six locations shown as numbered red and orange symbols in Fig. 8 and Fig. 9, with 66,528 individual T_{air} measurements.

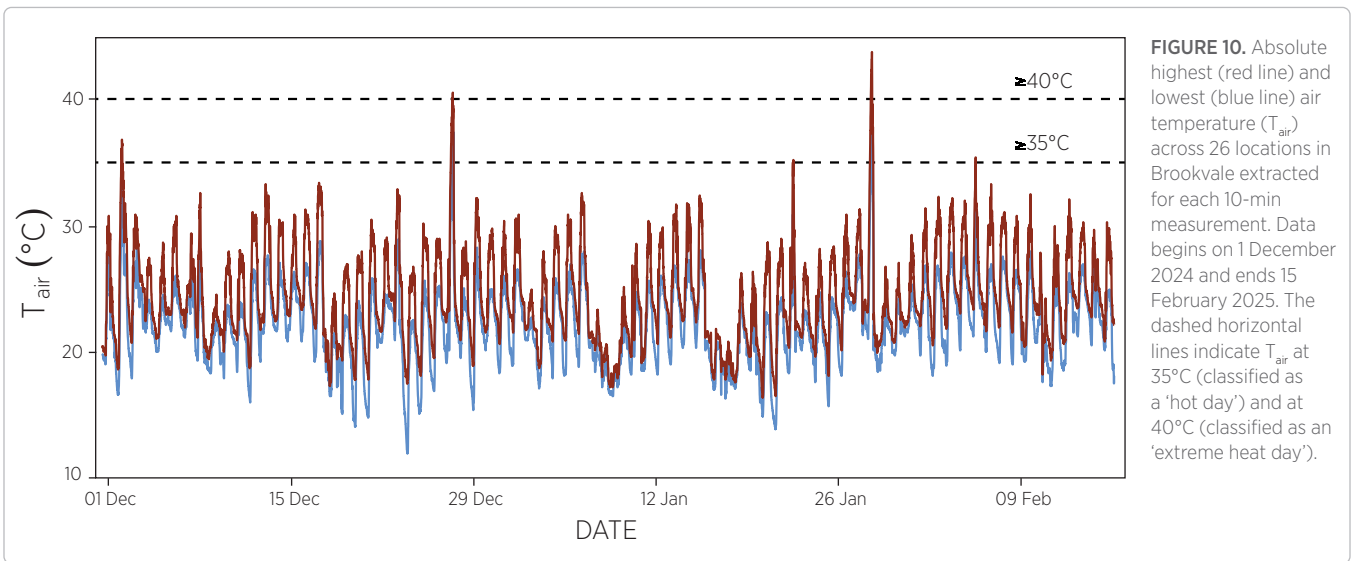
The analyses investigated air temperature variation across Brookvale including measurements of average air temperature (T_{mean}), minimum daily air temperature (T_{min}), maximum daily air temperature (T_{max}), the mean air temperatures during daytime (T_{daytime} , 10:00–18:00 hours) and nighttime hours ($T_{\text{nighttime}}$, 21:00 one day to 05:00 the next day).

3.3. MICROCLIMATE MAPPING

Microclimate maps with interpolated data were created using the ggplot2 R package and the @mapbox open-source satellite imagery was used for background maps. Temperature derivatives from measured data for each pixel between the physical locations were interpolated using the inverse distance weighted (IDW) interpolation. This method was used to create a continuous raster for the suburb, using a minimum of 10 and a maximum of 12 neighbouring measurement points. The results were interpolated in a grid at resolution of 1 pixel.



4. RESULTS



4.1. SUMMER AIR TEMPERATURES

Between 1 December 2024 and 15 February 2025, the average air temperature across 26 locations in Brookvale was 23.4°C. January was the coolest month (22.7°C), followed by December (23.6°C) and February was the warmest (24.5°C for the first 15 days). The maximum daily air temperature (T_{max}) exceeded 35°C on 5 days, and 40°C on 2 days (Fig. 10). The coolest day was 8 January 2025

with a mean temperature of 18.4°C when calculated across 24 hours and all locations. By contrast, the warmest day was 27 December 2024 when overall mean air temperature across the suburb was 26.9°C. Figure 10 shows a significant thermal variability across Brookvale as indicated by the overall differences between the locations with the lowest and highest air temperatures (T_{air}).

4.2. STREAM 1

4.2.1 INTRA-URBAN AIR TEMPERATURE VARIATION

Across the 77 days and for the individual locations, the mean air temperatures (T_{mean}) ranged from the lowest of 22.6°C to the highest of 23.9°C (Table 1). The air at Clearview Place (#13) was the coolest (22.6°C), followed by Old Pittwater Road (#14, 22.8°C) about 300 m southeast. Both locations were in the western part of the suburb, close to the forested area of Allenby Park and Brookvale Creek. Clearview Place also had the absolute lowest air temperature (T_{min}) of 12.1°C, measured on 24 December 2024.

Dale Street near Cross Street (#6) was the warmest location in the suburb with a T_{mean} of 23.9°C, which was 1.3°C warmer than the coolest place near the forest. There were seven other locations where the T_{mean} was almost as high (23.7°C). All eight of these warm sites were in the south and southeastern part of the suburb, where compact industrial space was dominant and green infrastructure was limited to small street trees. Mitchell Road (#22) was among the warmest places and recorded the absolute maximum air temperature (T_{max}) of 43.7°C on 28 January 2025.

TABLE 1. Mean (T_{mean} , °C), absolute minimum (T_{min} , °C) and maximum (T_{max} , °C) air temperatures of the 26 locations across Brookvale suburb in Stream 1. Data was recorded between 1 December 2024 and 15 February 2025. T_{mean} for each location was calculated using 11,088 measurements. The locations are ranked from the highest to the lowest T_{mean} .

LOGGER ID	LOCATION	T_{mean}	T_{min}	T_{max}
6	Dale Street	23.9	16.0	40.8
9	West of Roundabout at the Mall	23.7	15.5	42.8
21	Winbourne Road	23.7	15.7	41.8
27	Orchard Road	23.7	16.3	41.3
7	Roger Street	23.7	15.3	42.9
11	Cross Street	23.7	15.0	41.7
12	Old Pittwater Road	23.7	14.7	42.2
24	Miles Street	23.7	16.4	40.4
22	Mitchell Road	23.6	15.3	43.7
1	B-Line Bus Stop South	23.6	14.8	41.7
16	Dale Street	23.6	16.1	42.0
30	Short Street	23.5	15.1	41.9
26	Orchard Road	23.5	15.8	41.0
15	Roger Street	23.5	15.4	42.8
19	Winbourne Road	23.4	16.1	41.3
20	Mitchell Road	23.4	15.8	41.8
17	Roger Street	23.4	15.6	41.7
18	Dale Street	23.3	15.9	41.8
2	Mall South	23.3	14.0	40.6
28	Orchard Road	23.3	16.4	39.9
23	Winbourne Road	23.3	15.0	41.3
29	Wattle Road	23.2	15.3	41.5
10	Cross Street/Green Street	23.1	15.6	40.9
25	Ada Avenue	23.0	15.7	38.8
14	Old Pittwater Road	22.8	14.0	40.3
13	Clearview Place	22.6	12.1	41.3

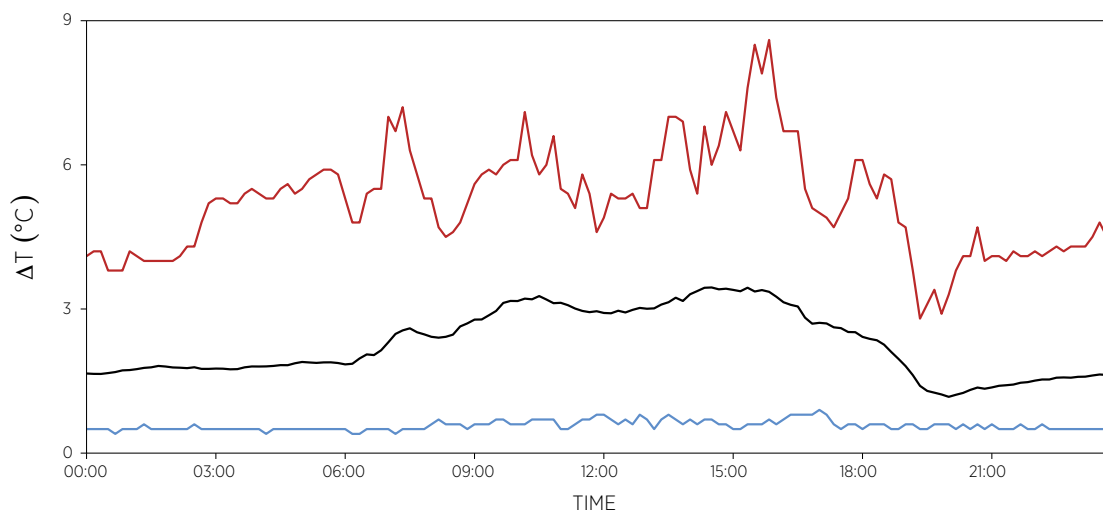


FIGURE 11. The temperature differential (ΔT) across 26 locations in Brookvale, calculated as difference between the highest and lowest temperature measurement at each 10-minute measurement. ΔT was averaged across the 77 days for each time point. The solid line indicates the mean ΔT , while the blue and red lines refer to the lowest and highest ΔT recorded between locations on individual dates.

Given the overall thermal differences between the locations within a relatively small but highly industrialized suburb, the influence of the time of day on T_{air} was further analyzed. This was done by extracting locations with the lowest and highest T_{air} for each 10-min measurement. The lowest value was subtracted from the highest T_{air} measurement to calculate temperature differentials (ΔT) which subsequently were averaged across each of the 144 10-minute time points for the 77 measurement days.

The analysis showed that the differences were smaller at night than during the day (Fig. 11). The ΔT was relatively constant before sunrise and after sunset, oscillating around 1.7°C. This small differential indicated that the locations were close to equilibrium, a consequence of the lack of solar radiation. As indicated in Figure 11, the average nighttime urban heat island effect on air temperature (UHIE_{a}) was around 2°C, but was above 5.0°C during selected nights

(red line indicating maximum ΔT). For instance, at the western end of Orchard Road (#28) T_{air} was 17.7°C at 04:40 hours on 24 December 2024, while the T_{air} was 12.1°C at Clearview Place (#13). Both locations had a significant proportion of hard surfaces, but a pocket of mature street trees with dense crowns on Orchard Road most likely kept nighttime air temperatures high. At the same time Clearview Place was more open than Orchard Road and close to the forested area, which probably improved heat dissipation, nighttime cooling and cool air flows.

After sunrise, ΔT increased gradually and reached the highest mean value of 3.4°C between 14:00 and 16:00 hours (Fig. 11). The increase in thermal differences among locations was driven by the solar radiation impacting various surface types that led to the rise in air temperatures. This was particularly significant for sites with a large proportion of hard infrastructure, whereas locations with

more green infrastructure nearby were less impacted. Such situation frequently occurred between warm locations 1, 7, 9, 12, 22 and cool sites 17, 24, 25, where the absolute maximum ΔT exceeded 6.0°C on several occasions. In many cases, the sea breeze was driving that significant thermal difference across the suburb, resulting in a hotter western section of the precinct compared to the east. For example, the highest differential of 8.6°C (red line in Fig. 11) was observed between Old Pittwater Road in the west (#12, 40.4°C) and Miles Street in the east (#24, 31.8°C) at 15:50 on 27 December 2024. This was a time of the day when the sea breeze kept the eastern location almost 10°C cooler than in the west. In the evening, the differentials sharply declined as the sun was lower and the influence of solar radiation on microclimates was reduced. The presence of the sea breeze is discussed later in this report.

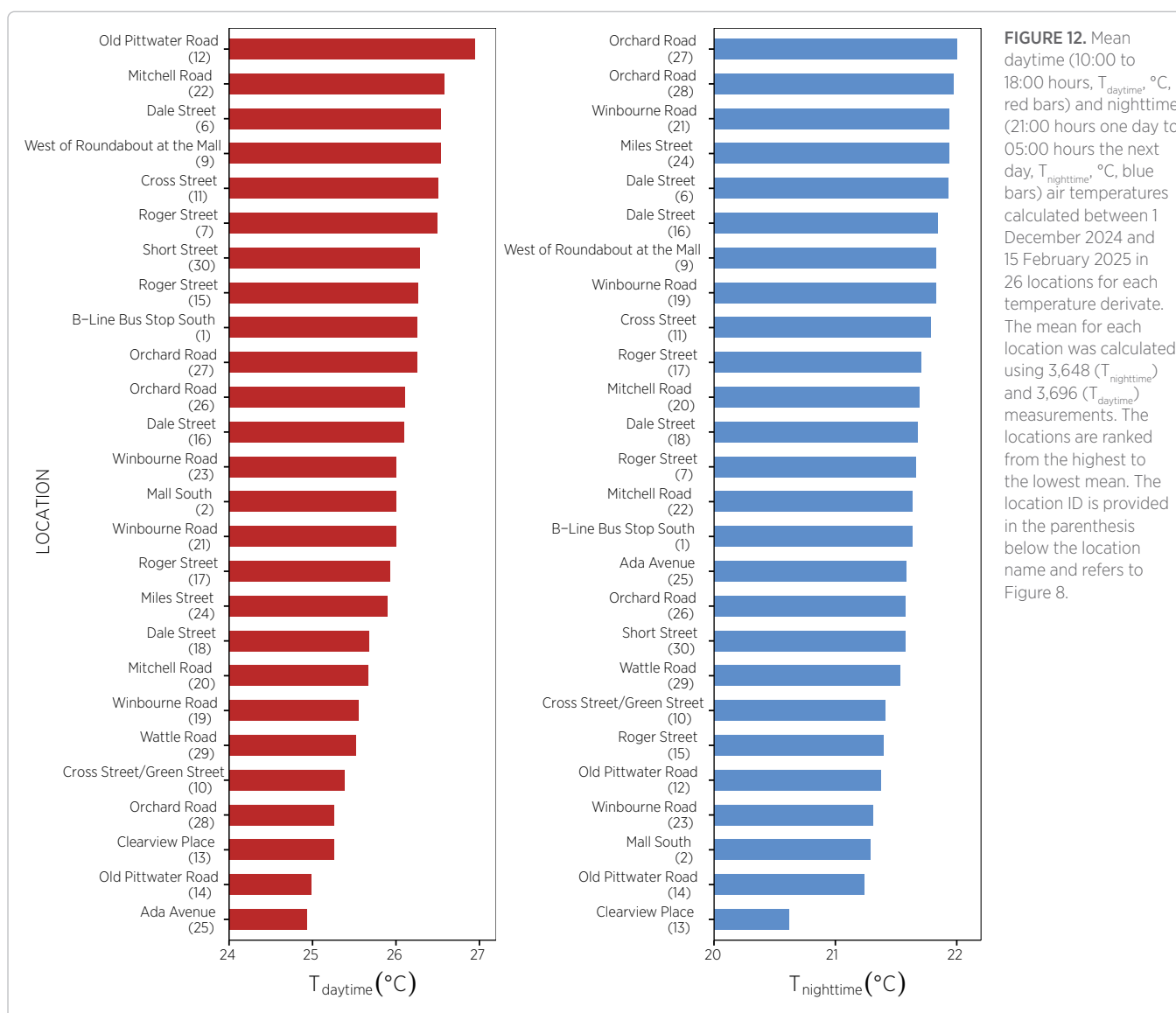
Daytime temperatures were calculated as the mean of the 8 hours between 10:00 and 18:00 hours (T_{daytime}). Nighttime temperatures were calculated as the mean of the 8 hours from 21:00 hours on one day to 05:00 hours the following day ($T_{\text{nighttime}}$). The number of hot days ($T_{\text{max}} \geq 35^{\circ}\text{C}$), extreme heat days ($T_{\text{max}} \geq 40^{\circ}\text{C}$), and warm nights ($T_{\text{min}} \geq 20^{\circ}\text{C}$) was also determined for each location (see Table A2 in the Appendix).

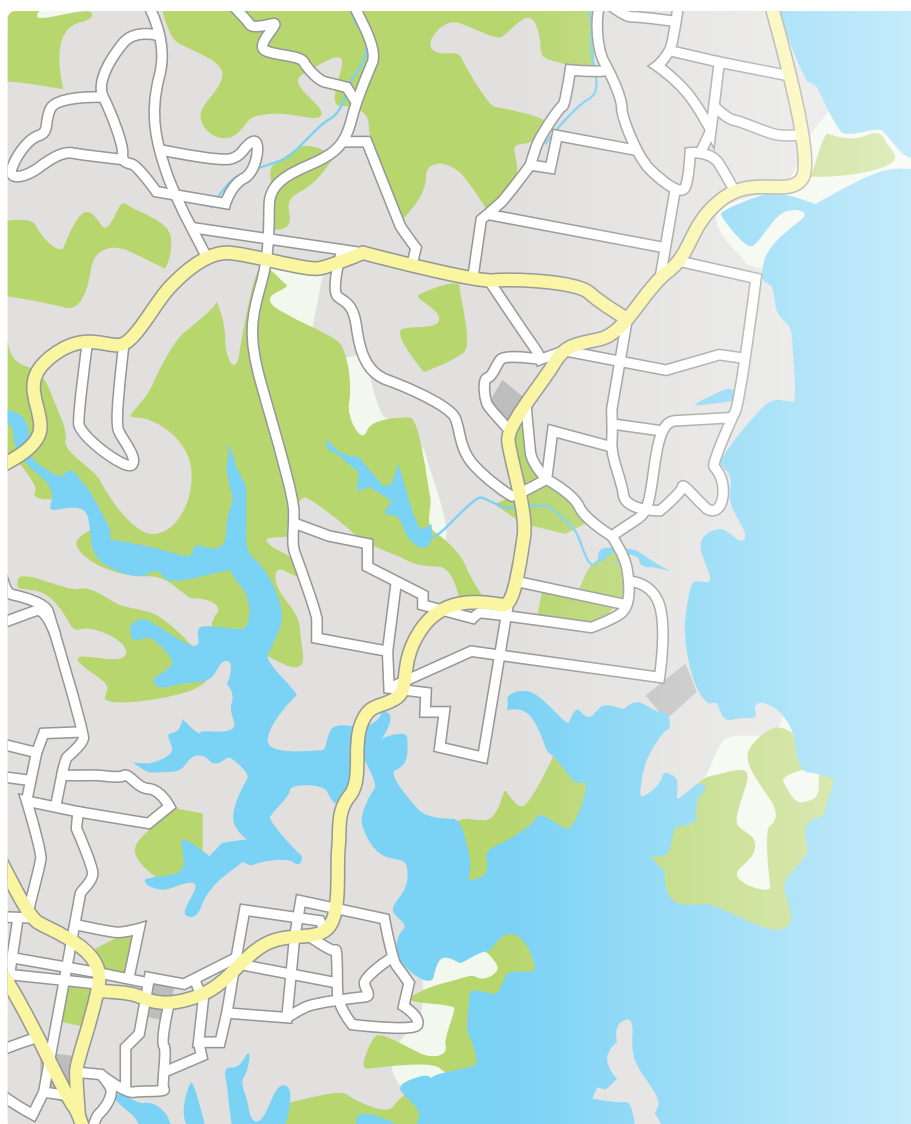
The daytime temperatures were the lowest at Ada Avenue (24.9°C , red bars in Fig. 12), where temperatures were measured underneath large trees with dense crowns and a wide nature strip underneath. Other places with low T_{daytime} were Clearview Place and the western section of Orchard Road where tree canopy cover was high. All these locations had also the coolest afternoons (Fig. 12). The warmest daytime temperatures were recorded at the southern end of Old Pittwater Road where T_{daytime} was 2.0°C warmer compared to Ada Avenue. Five other sites, mainly in the centre and eastern industrial area were also among the warmest during the day.

The warm section of Old Pittwater Road, but also Roger Street and Mitchell Road recorded four hot days, while 14 other locations only recorded 3 hot days. Also, the number of extreme heat days was the highest ($n = 2$) at the southern part of Old Pittwater Road. In contrast, no extreme heat days were recorded at Ada Avenue and the western part of Orchard Road.

Nights were the coolest in Clearview Place (20.6°C), followed by north Old Pittwater Road (21.2°C) (blue bars in Fig. 12). Drainage of cool air from the nearby forested area is most likely the cause of the cool nighttime air temperatures. By contrast, $T_{\text{nighttime}}$ was the highest at two sites on Orchard Road (22.0°C), where nights were 1.4°C warmer. Locations in Orchard Road, and also Miles Street, Winbourne Road and Dale Street recorded 52 warm nights where air temperatures were at or above 20°C , while at Clearview Place only 28 such nights were recorded.

These findings clearly highlight the cooling effect of green infrastructure during the day. The locations with the lowest air temperatures in the afternoons and during the day generally had many more trees with dense canopies, which meant that shade kept surfaces and the air cooler. However, dense canopies led to slight nighttime warming in some of these locations, which is expected and was reported for other locations in Greater Sydney by the research team. Overall, the cooling benefits from dense canopies during the day usually outweigh the small nighttime warming.





4.2.2 MICROCLIMATE MAPS

Selected air temperature derivatives were used to visualise thermal conditions across Brookvale using unique, data-based microclimate maps. These are shown as map products for mean summer air temperature (Fig. 13), mean daytime air temperature (Fig. 14), and mean nighttime air temperature (Fig. 15). These maps contain measured data from 26 locations with a 10 m buffer around the suburb boundary. The maps depict the following generalised observations.

- Areas near residential developments in the northwest and southeast had lower summer mean air temperatures (T_{mean}) than the industrial areas in the centre of the suburb east of Pittwater Road (Fig. 13).
- Mean daytime air temperatures (T_{daytime}) were warmer in the southwest near the shopping mall compared to the northwest and southeast near residential areas (Fig. 14).
- Mean nighttime air temperatures ($T_{\text{nighttime}}$) were lower at the edge of Allenby Park in the northwest residential area than across the industrial developments in the east and southeast (Fig. 15).
- Summer mean, day- and nighttime air temperatures were generally lower when measurement locations were in proximity of green-blue corridors (i.e., Allenby Park and Brookvale Creek in the west, Warringah and Manly golf courses and Brookvale Creek in the south, sport spaces and Greendale Creek in the west - Figs 13-15).



FIGURE 13. Mean summer air temperature (T_{mean} , °C) across Brookvale between 1 December 2024 and 15 February 2025. The solid white line indicates the suburb boundary (Australian Bureau of Statistics, 2021), and the background is satellite map from @mapbox. Data was interpolated using measurements from 26 locations across the area. The coolest summer means were near residential developments in the northwestern and southeastern part of the suburb, while the hottest area was near the shopping centre west of Pittwater Road.

**FIGURE 14.**

Mean daytime air temperature (T_{daytime} , $^{\circ}\text{C}$) across Brookvale between 1 December 2024 and 15 February 2025. The solid white line indicates the suburb boundary (Australian Bureau of Statistics, 2021), and the background is satellite map from @mapbox. Data was interpolated using measurements from 26 locations across the area. The hottest area during daytime hours was in the southwestern part of the suburb, just south of the shopping centre. The coolest areas were in the southeastern and northwestern corners of the suburb.

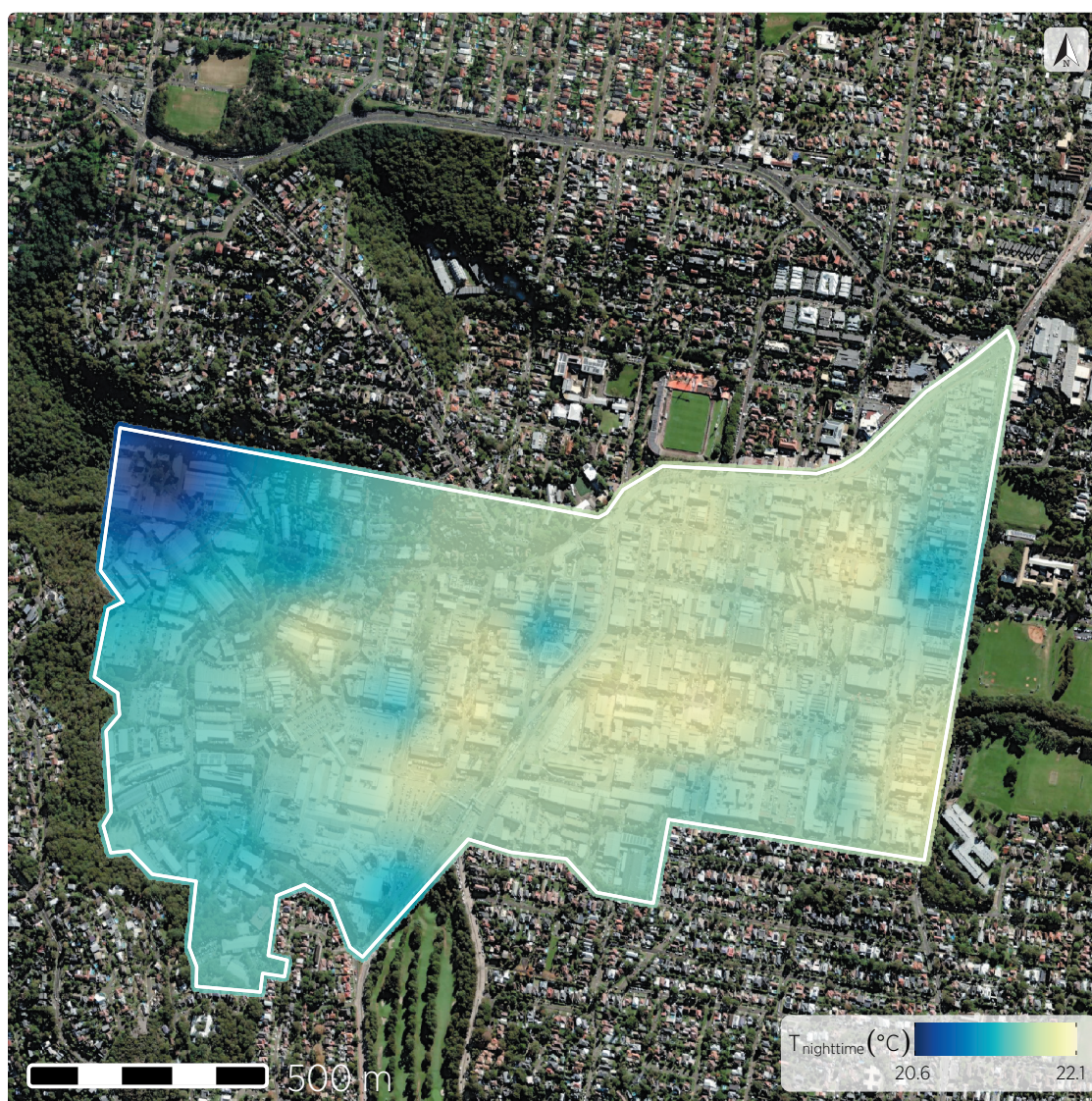
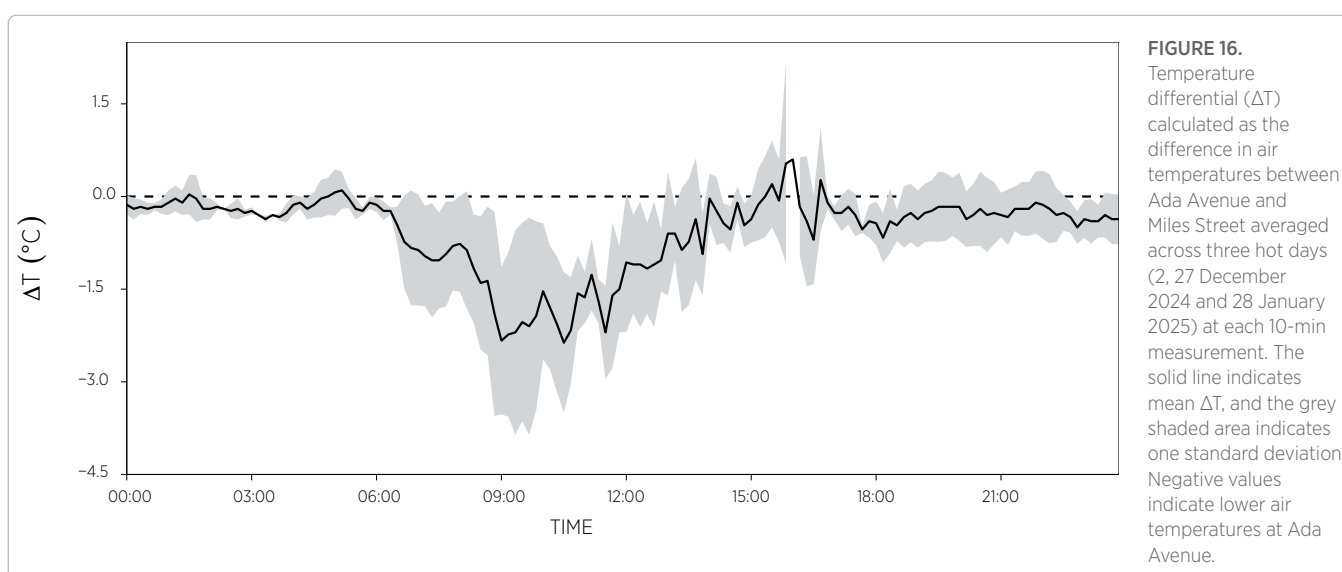


FIGURE 15. Mean nighttime air temperature ($T_{\text{nighttime}}$ °C) across Brookvale between 1 December 2024 and 15 February 2025. The solid white line indicates the suburb boundary (Australian Bureau of Statistics, 2021), and the background is satellite map from @mapbox. Data was interpolated using measurements from 26 locations across the area. The coolest nights were in a small localised area in the very northwesternmost part of the suburb, while the warmest nighttime air temperatures were measured within the industrial developments, especially to the east of Pittwater Road.



4.2.3. GREEN LINKS AND SEA BREEZES

Notable differences in microclimates were measured in the future Green Link streets, marked as green dashed lines in Figure 5. Miles Street and Ada Avenue are intersecting roads, with air temperature loggers located less than 200 m apart. Both locations are close to the John Fisher Reserve and the vegetation associated with Greendale Creek in the southeastern part of the suburb. Despite the small distance between the two measuring points, Ada Avenue was consistently cooler

than Miles Street. Across the summertime, the difference was on average 0.7°C , ranging from 0.2°C to 1.0°C depending on the day. The differences were greatest during the daytime hours, when Miles Street was around 1.0°C warmer than Ada Avenue, but the thermal difference was smaller during the night (on average 0.4°C). On the three dates when the T_{max} was at or above 35°C at these locations, air temperatures at Ada Avenue were consistently lower than those at Miles Street throughout the 24-hour period (Fig. 16). At night, the ΔT was small and varied between 0°C and -0.5°C .

The largest thermal difference between the neighbouring streets was in the morning hours of the hot days, reaching as low as -2.4°C at 10:30 hours. ΔT decreased towards the afternoon when both streets had comparable T_{air} . The presence of wide green street verge and large tree canopies on Ada Avenue was the likely reason for less heat absorption by the hard surfaces along this street. Conversely, Miles Street had less green infrastructure, which resulted in warming of the air, particularly in the morning hours.



FIGURE 17. Microclimate maps depicting the three distinctly different phases that unfold across Brookvale during hot summer intervals. **(A) Phase 1:** During the late night and early morning (map shows 04:00 hours), cool air drains down the escarpment from the northwest (Allenby Park) into the western part of the suburb where air temperatures are lowered; a noticeable UHIE_g is present in the eastern section where nighttime air temperatures remain warmer compared to the west; the colour scale for air temperature spans 3.2°C. **(B) Phase 2:** During the morning and into midday, air temperatures across the precinct equilibrate (map shows 12:10 hours); the colour scale for air temperature spans 2.5°C. **(C) Phase 3:** The sea breeze lowers air temperatures in the east while from Pittwater Road to the west air temperatures remain high (map shows 15:40 hours); the entry point of the cooler air from the sea breeze travelling up the green corridor to the ease is clearly visible; the colour scale for air temperature spans 7.9°C. Data depicts conditions on 27 December 2024, a very hot day where air temperatures reached 40.5°C.

Sea breezes are an important microclimatic feature along the coastal fringe zone of Sydney, including the Northern Beaches LGA. Thermodynamic processes, driven by temperature changes between land and sea, result in changes of air flows in vertical (convective flows) and horizontal direction (advective flows).

To generate a cooling sea breeze at Brookvale requires strong convection of warm air above the built environment to force cool air advection for 2-3 km from the sea inland. Brookvale is well positioned to generate this advective air flow due to its low canopy cover and resultant high surface temperatures. However, the suburb has a natural feature that is worth highlighting: the connection of its eastern and southern boundary to the ocean via wide green-blue corridors. Cool air masses can travel unobstructed from the sea at North Curl Beach, up the Curl Curl Lagoon and along Greendale Creek for 2 km inland without being warmed by grey infrastructure. This setting represents an unusual and highly effective natural feature that provides Brookvale with strong westerly cooling sea breezes. In addition, the combination of golf courses and green reserves at the southern end of Warringah Mall, in combination with the associated water bodies of Brookvale Creek, Manly Creek and Manly Lagoon offer a second gateway for cool winds from a southerly direction. These types of cooling winds may be less regular than sea breezes, yet can represent an important local air flow during heatwaves. The cooling effect of the 'Southerly Buster', a wind associated with a strong cold front, is well known as weather phenomenon across Greater Sydney at the end of heatwaves.

This research project has detected the strongest sea breezes during the hottest days when the sky was clear. Slow moving sea breeze cooling was detected on the 600 m long Orchard Road, where air temperatures during the early afternoon of 2 December dropped from east to west by 5°C within less than one hour. Similarly, but much faster were reductions of air temperature along Winbourne Road. Both streets were oriented east-west, allowing for fast progression of air streams. Yet Winbourne Street was much wider than Orchard Road and had much lower tree canopy cover which would not have slowed down air flows. No such gradual or fast changes were detected in streets oriented north-south (e.g., Roger and Dale St).

Cooling sea breeze effects were most pronounced during hot days. This is no surprise as the high surface temperatures provided a strong driving force for the convective air flow over Brookvale. Generally, three phases that differ markedly in their thermal characteristics can be distinguished (Fig. 17). During Phase 1 (Fig. 17A), cold air drains from the bushland in the west down the escarpment and into the north-western section of the suburb. This phase is most pronounced during the late night and early morning hours. After the sun rises, the entire suburb begins to warm and air temperatures begin to equilibrate. On a warm or hot day, air temperatures between 09:00 and 13:00 hours are unlikely to be much different anywhere in Brookvale. This is Phase 2 (Fig. 17B). If the sky remains clear and air temperatures rise, Phase 3 unfolds (Fig. 17C), which results in clear thermal discrepancies between eastern and western parts of Brookvale. Depending on the intensity

of the cooling sea breeze, warm air is replaced with cool air until Pittwater Road or even a few streets further to the west. Once the sea breeze has lowered air temperatures and surface temperatures decline due to the descent of the sun towards sunset, Phase 2 would return to see air temperatures equilibrate across the suburb. Later during the night, the cold air flows from the escarpment would signify the onset of Phase 1.

Generally, our analyses of cooling sea breezes from the east during the day and also the cold air drainage from the west during the night indicate that heat-sensitive urban planning should consider strategies that support natural ventilation (i.e., cooling) of Brookvale. Possible choke points could be removed and green-blue corridors established to support east-west air flows along streets with ample canopy cover. Due to its location and topography, harnessing these air flows for passive cooling seems a logical focus for the upcoming development/renewal process in the area. In addition, any means to generate thermal benefits from the substantial area of green spaces and water bodies in the south should be considered.

4.2.4 COMPARISONS BETWEEN RESIDENTIAL AND INDUSTRIAL SPACES

Microclimates within two residential areas were compared with microclimates in two industrial spaces. The residential locations were near low (Short Street, #30) and medium density buildings for residents (Old Pittwater Road, #14). The section of Old Pittwater Road where the measurements were taken was oriented east-west and had a substantial tree canopy cover, whereas Short Street had been oriented north-south. More compact retail and industrial infrastructure was dominant along Dale and Roger Streets in the centre of the suburb. Those two streets had mainly hard surfaces and buildings with limited green infrastructure, and they were both oriented north-south.

During the day, the medium density residential on Old Pittwater Road was on average 1°C cooler than the industrial and retail spaces along Dale and Roger Streets. This was also true for Short Street at the edge of the low density residential area in the south. These results suggest that high tree canopy and

more green infrastructure generally in the form of residential front and back gardens. The east-west street orientation also could have contributed to more efficient movement of cooler air from the coast. Conversely, limited tree canopy and the dominance of grey infrastructure surrounding the two measurement locations in the industrial area most likely absorbed and stored heat throughout the day, increasing the local air temperatures. The north-south orientation of those streets did not support unhindered movement of cooler air coming from the coast.

The medium residential area also remained cool at night, which could be explained by the lower daytime temperatures and cool air drainage from the escarpment in the west. Short Street had also lower temperatures during nighttime hours, which could be a result of more open and green space across the low-density residential area, which allowed for efficient heat dissipation and nighttime cooling. In contrast, the two measurement locations in the industrial and streets were warmer throughout the day and at night.

4.3. STREAM 2 – FUTURE TOWN SQUARE

The microclimate of the at-grade car parks near the Warringah Mall was relatively uniform across the summertime. T_{mean} varied from 23.3°C to 23.7°C (Table 2). The location west of the central roundabout had the highest T_{mean} of 23.7°C, which was only 0.4°C warmer than the car park at the front of Bunnings 100 m to the northeast. The location closest to the roundabout was the hottest. Here T_{max} was 42.8°C at 13:30 hours on 28 January 2025. At that time, air temperatures under the group of native trees north of the B-Line bus stop on Pittwater Road were 2.5°C lower.

TABLE 2. Mean (T_{mean} , °C), absolute minimum (T_{min} , °C) and maximum (T_{max} , °C), daytime (T_{daytime} , °C) and nighttime ($T_{\text{nighttime}}$, °C) air temperatures of the 6 locations across at-grade car park at Warringah Mall in Stream 2. Data was recorded between 1 December 2024 and 15 February 2025. T_{mean} for each «measurements. $T_{\text{nighttime}}$ was calculated between 21:00 and 5:00 hours ($n = 3,648$), and T_{daytime} was calculated between 10:00 and 18:00 hours ($n = 3,696$).

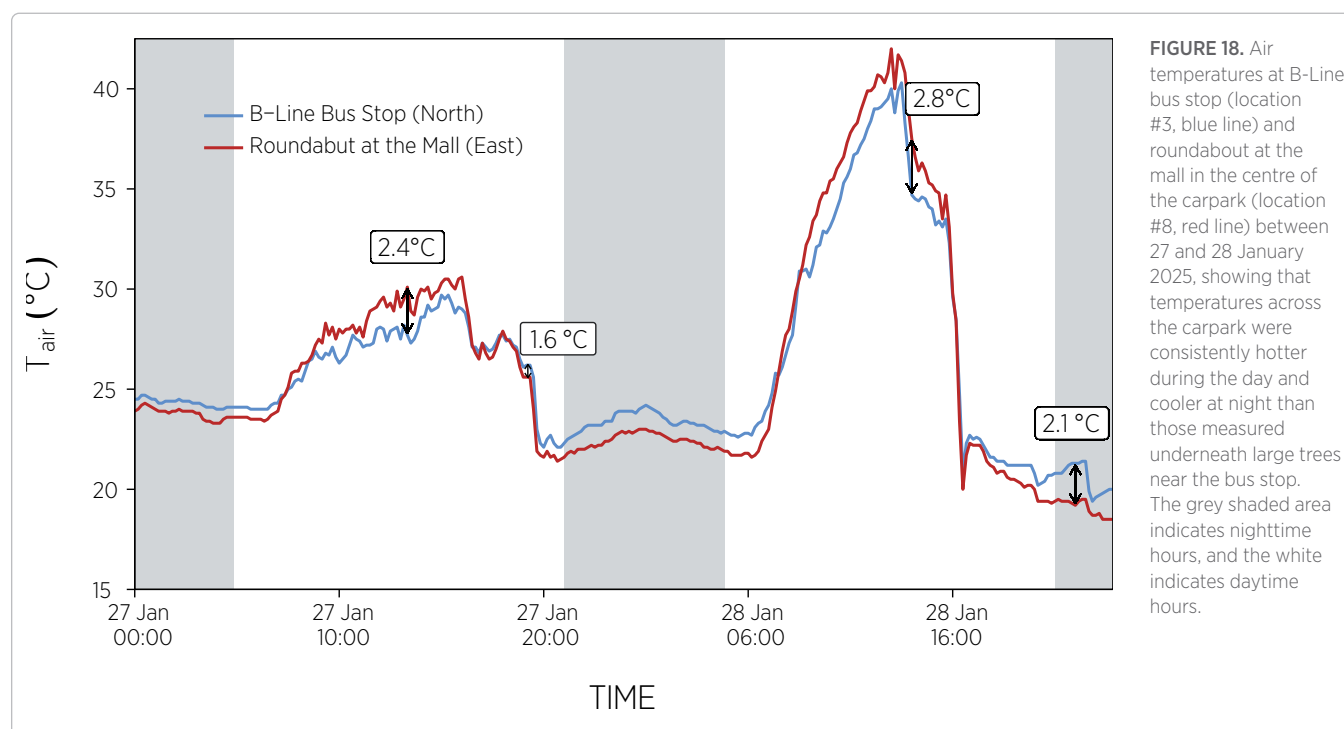
Logger ID	Location	T_{mean}	T_{min}	$T_{\text{nighttime}}$	T_{max}	T_{daytime}
1	B-Line Bus Stop South	23.6	14.8	21.6	41.7	26.3
3	B-Line Bus Stop North	23.5	15.6	21.9	40.3	25.7
4	Bunnings Entry	23.3	15.3	21.4	41.2	25.7
5	Mall entry at Cross Street	23.6	15.6	21.7	41.2	26.5
8	East of roundabout at the Mall	23.5	14.2	21.1	42.0	26.7
9	West of roundabout at the Mall	23.7	15.5	21.8	42.8	26.5

The air temperature differences between Sites 3 and 8 were further investigated to identify the magnitude of air temperature difference on the hottest day in this study. On 27 January 2025, the air temperatures were around 30°C

in the centre of the carpark, while the tree shade near the bus stop reduced the T_{air} by as much as 2.4°C (Fig. 18). On the hottest day, 28 January, the shade cooling benefit was even greater with up to 2.8°C lower T_{air} near

the bus stop than at the roundabout/carpark. These results are significant, given the locations were only 70 m apart. The fact that these two locations were so close to each other, yet had very different microclimates, especially during hot days, highlights the importance of shading car parks to reduce absorption and re-emission of solar radiation and associated warming of the surrounding air.

Although trees reduced daytime air temperatures near the bus stop, the air was warmer underneath the canopies in the morning and at night. That warming reached up to 1.6°C (27 January) and 2.1°C (28 January). Given that this area was less likely to be used at night than during the day, the shade cooling benefits provided by trees during the daytime were likely more important than a small nighttime warming effect.



5. RECOMMENDED ACTIONS

In taking the pulse of urban heat in Brookvale, this work helps to answer the question - what can the Northern Beaches Council do to build resilience to urban heat? From the measurement and analyses of summer air temperatures across the suburb of Brookvale, the following considerations and recommendations arise.

- Tree species selection – choose species with canopies that are large and dense so they provide effective daytime cooling.
- Street orientation and building heights – consider street orientation and building heights that will facilitate air movement to maximise the cooling effect of the sea breeze.
- Increase tree canopy cover and other means of air cooling (e.g., engineered solutions) in selected streets where locations were detected with the highest mean air temperatures (e.g., Dale Street near Cross Street and the roundabout at Warringah Mall) where high daily mean maximum air temperatures were recorded (e.g., on Mitchell Road and Roger Street).

Using information from the wider scientific and non-scientific literature that addresses issues relating to urban heat and cooling strategies, the following additional actions will assist the Northern Beaches Council to build heat resilience.

1. Continue to measure and monitor urban air temperatures and heat island effects. This has been done in cities including Basel and Zurich in Switzerland (Anet et al., 2021) to demonstrate the efficiency of mitigation actions.
2. Implement 'top-down' actions to reduce UHIE_a including
 - application of biophilic design principles (e.g., provide more natural and engineered shade, install green roofs and walls),
 - incorporation of water in urban design (e.g., use irrigated greenspaces, drinking water bubblers, raingardens, bioswales, passive street tree irrigation pits, splash parks),
 - 'day-lighting' hidden creeks and waterways with great opportunities for Brookvale Creek
 - depave hard, impervious surfaces to become permeable and ideally vegetation-covered spaces,
 - reduce the use and increase the reflectivity of dark surface materials on roads, sidewalks and carparks, and
 - further encourage active transport across the LGA to reduce waste heat from traffic.
3. Support 'bottom-up' actions for urban cooling including:
 - support property owners to increase greening through policies (e.g., tree removal permit requirements), planning and incentives, decrease hard/impervious surfaces on private land, decrease use of air conditioners at homes and cars for transport (support use of bikes, walking etc.), and
 - provide free trees and consultation for homeowners that ensures an appropriate strategy is in place that matches trees with planting locations and canopy expansion forecasts.
4. Protect communities during extreme heat events and heatwaves by
 - applying a HeatReady Neighbourhood planning rubric (see Guardaro et al., 2024), which prioritises hyperlocal, neighbourhood-scale needs to enable communities to optimise their social, physical and natural assets for improved resilience to extreme heat and other natural hazards, and
 - providing and promoting the use of cool zones or 'urban climate shelters' (Amorim-Maria et al., 2023). Climate shelters are elements of the urban infrastructure such as parks, libraries, civic centres, where people can take refuge during episodes of extreme temperatures. Development of shelters should address the intersection of social and climate needs of residents and visitors who need them most – not everyone can spend time on the beach.
5. Integrate climate adaptation services into local urban planning using examples from the ReachOut project (ReachOut, 2023) to "guide complex decision-making processes where multiple challenges such as spatial planning, mobility, housing, urban greening, climate mitigation and climate adaptation are interacting".



6. CONCLUSION

This research has demonstrated patterns of microclimatic variation within the Northern Beaches industrial heartland of Brookvale. Microclimates at single locations as well as temperature and patterns across the suburb were identified from empirical and highly granular measurements made with custom-made microclimate loggers. Places and areas with the warmest summer air temperatures have been identified, and the data revealed large variation in thermal conditions across Brookvale. Such variation is the driver of climate inequality for residents and workers.

The Brookvale Structure Plan aims to address urban heat through actions including development of Green Links that will be landscaped and planted with street trees. These strategies will help lower air temperatures, provided the trees have sufficient space to spread and develop dense crowns. Successful tree establishment and maintenance will require the preparation and implementation of an Urban Tree Canopy and Greening Strategy for Brookvale as noted in the BSP.

The recent State of the Climate report shows the urgency required to both mitigate and adapt to the warming climate with continuing increases in air temperatures and more heat extremes during summer (Commonwealth of Australia, 2024). In the coming decades, Australia will continue to experience changes to weather patterns and climatic conditions, with long-term trends showing most years are now warmer than almost any of those observed during the 20th century (Commonwealth of Australia, 2024). Results from this study will help the Northern Beaches Council to continue and broaden its programs and efforts to establish a climate-resilient community for residents both now and in the future.



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8. APPENDIX

TABLE A1. Details of the locations of the 30 microclimate loggers used in Streams 1 and 2 of the heat benchmarking study in Brookvale.

LOGGER ID #	LOCATION	LATITUDE	LONGITUDE	STREAM
1	B-Line Bus Stop South	-33.7678	151.2681	1 and 2
2	Mall South	-33.7690	151.2668	1
3	B-Line Bus Stop North	-33.7669	151.2688	2
4	Bunnings Entry	-33.7664	151.2685	2
5	Mall entry at Cross Street	-33.7660	151.2683	2
6	Dale Street	-33.7656	151.2684	1
7	Roger Street	-33.7657	151.2696	1
8	East of Roundabout at the Mall	-33.7670	151.2681	2
9	West of Roundabout at the Mall	-33.7668	151.2673	1 and 2
10	Cross and Green Street	-33.7655	151.2667	1
11	Cross Street	-33.7642	151.2648	1
12	Old Pittwater Road	-33.7681	151.263	1
13	Clearview Place	-33.7611	151.2613	1
14	Old Pittwater Road	-33.7626	151.2643	1
15	Roger Street	-33.7641	151.2701	1
16	Dale Street	-33.7644	151.2687	1
17	Roger Street	-33.7627	151.2703	1
18	Dale Street	-33.7633	151.2687	1
19	Winbourne Road	-33.7621	151.2737	1
20	Mitchell Road	-33.7617	151.2747	1
21	Winbourne Road	-33.7628	151.2771	1
22	Mitchell Road	-33.7636	151.2746	1
23	Winbourne Road	-33.7630	151.2789	1
24	Miles Street	-33.7669	151.2786	1
25	Ada Avenue	-33.7673	151.2767	1
26	Orchard Road	-33.7660	151.2764	1
27	Orchard Road	-33.7655	151.2736	1
28	Orchard Road	-33.7653	151.2717	1
29	Wattle Road	-33.7673	151.2736	1
30	Short Street	-33.7687	151.2727	1

TABLE A2. The number of hot ($\geq 35^{\circ}\text{C}$) and extreme heat days ($\geq 40^{\circ}\text{C}$), and warm nights ($\geq 20^{\circ}\text{C}$) air temperatures calculated for 26 locations across Brookvale in Stream 1. The locations are ranked from the highest to the lowest number of hot days.

LOGGER ID #	LOCATION	DAYS ABOVE $\geq 35^{\circ}\text{C}$	DAYS ABOVE $\geq 40^{\circ}\text{C}$	NIGHTS ABOVE $\geq 20^{\circ}\text{C}$
12	Old Pittwater Road	4	2	41
15	Roger Street	4	1	44
22	Mitchell Road	4	1	46
2	Mall South	3	1	39
7	Roger Street	3	1	45
9	West of Roundabout at the Mall	3	1	50
10	Cross Street/Green Street	3	1	45
18	Dale Street	3	1	50
19	Winbourne Road	3	1	52
20	Mitchell Road	3	1	51
21	Winbourne Road	3	1	52
23	Winbourne Road	3	1	43
24	Miles Street	3	1	52
26	Orchard Road	3	1	46
27	Orchard Road	3	1	52
29	Wattle Road	3	1	46
30	Short Street	3	1	43
1	B-Line Bus Stop South	2	1	45
6	Dale Street	2	1	51
11	Cross Street	2	1	45
13	Clearview Place	2	1	28
14	Old Pittwater Road	2	1	40
16	Dale Street	2	1	52
17	Roger Street	2	1	49
25	Ada Avenue	2	0	49
28	Orchard Road	2	0	52





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