Australia's National
Science Agency

Focus on Darwin

A conversation on changes in liveability, sustainability and resilience from 2011 to 2023

This e-book was delivered as part of the Darwin Living Lab and focuses on five important stories and conversations for Darwin.

01 Urban Heat Island

02 Healthy Outdoor Environments

03 Water is a Key Resource (for Cooling)

04 Sustainability: Towards Net-Zero

05 Indoor Liveability

The Darwin Living Lab is an initiative under the Darwin City Deal and is a 10-year collaboration between CSIRO and the partners of the Darwin City Deal: the Australian Government, Northern Territory Government and City of Darwin. The City Deal was signed by the Prime Minister of Australia, Chief Minister of the Northern Territory and Lord Mayor of the City of Darwin in November 2018.

More information, contacts, and a digital copy of this report are available at research.csiro.au/darwinlivinglab

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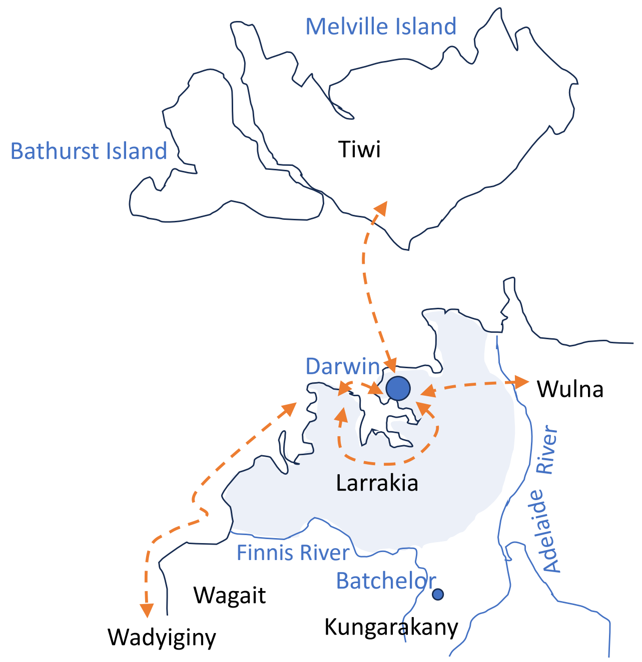
Overview of Darwin

Welcome to Larrakia

Co-authored by Lorraine Williams, Larrakia Elder

The Larrakia people are the traditional owners of the Darwin region, Cox Peninsula and Gunn Point region. Gulumoerrgin is the Indigenous language of the Larrakia people. The Larrakia people are referred to as saltwater people and are connected to the sea, the environment, the biodiversity, the land, the cosmos and everything in between.

Prior to European and Asian settlement, the Larrakia had established amicable relations with their Aboriginal neighbours, the Tiwi of the islands to the north, the Wagait to the south-west towards the mouth of the Daly River and the Wulna to Adelaide River to the east (see map). The Larrakia, along with many Aboriginal groups, have intermarried and shared in ceremonies, creating songlines and sharing in the rich cultural heritage and history of the area.



Since colonisation, the extinction of local plant and animal species has been observed by Larrakia people; this change has occurred through the destruction of lands and waterways, extensive development, fire, pests, weeds and natural disasters. With the increasing threat of climate change, Larrakia-led research continues to capture responses through surveys on biodiversity condition, and Larrakia rangers continue to monitor the behaviour of animals and native plants, flowers and fruits identified within the Gulumoerrgin seasonal calendar, to better understand changes in climate and seasonal shifts within Larrakia Country.

Darwin – a unique place with unique challenges

Darwin is a unique place, described by some authors as a charming Larrikin among the other Australian capitals.[1] Darwin Harbour was named by Lt. John Lort Stokes in 1839, believing that his colleague Charles Darwin would have been fascinated by the talc stone heads at its entrance.[2] In 1863, the South Australian Government sought to provide a northern harbour settlement; originally named Palmerston in 1869, it was renamed Darwin in 1911. Unlike other failed efforts to develop northern settlements (e.g. Fort Dundas, Fort Wellington, Victoria and Escape Cliffs), Darwin would be the place that prevailed, despite the extreme heat, relative isolation, mosquitoes, cyclones, World War II attacks, changes in governance and boom-bust economic cycles.[3,4]

Darwin continues to blossom. It is also at the centre of a lot of Australia's challenges: Indigenous reconciliation, national economic expansion, carbon emissions policy for regional Australia, trade with Asia and national defence.

National plans for Developing Northern Australia seek to lay the foundations for rapid population growth with a trajectory to reach a population of 4–5 million people living above the Tropic of Capricorn by 2060. What does this mean for Darwin? It is clearly an important part of the nation's future, but how does Darwin and its people take positive steps to grow its population while retaining and nurturing its character and values?

Change in Darwin will not only come through population growth – there are several existing and future challenges and questions that need to be considered.

- Darwin is a hot place and is predicted to get hotter. This places pressure on liveability and energy demand for cooling, and increases heat-health risks, noting that heatwaves have claimed more lives in Australia than all other natural hazards combined.[5]
- How does Darwin manage its urban footprint given that developable land is limited by waterlogged landscapes, and how can the city be developed to be more liveable for future Darwinites and be sensitive to its unique and much valued biodiversity?
- Darwin has high energy and water usage compared to other Australian cities. How does Darwin decarbonise and reduce carbon dioxide (CO_2) emissions when there is high demand for energy for air-conditioning to maintain thermal comfort?
- How does Darwin reduce oil-based transport emissions given the high use of sport utility vehicles (SUVs) and four-wheel drives (4WDs)?
- How can a water-sensitive approach enable a cooler and greener Darwin, supporting the need for more efficient water use in the landscape, and dealing with the extremes of the wet-dry tropical climate?
- Darwin experiences smoke pollution every dry season when the surrounding savanna experiences fires which results in particulate matter concentrations that regularly exceed Australian air-quality standards. How can government, land managers and the community better manage exposure to smoke pollution to provide a healthier and more liveable Darwin?

These and other challenges cannot be solved by simple solutions; they are complex due to their interrelated nature, and both social and technical issues need to be considered.

Decision-makers in the Top End are taking action and recognise that change needs to occur to address these challenges. The Darwin City Deal is a 10-year plan to position Darwin as a vibrant and liveable tropical capital city, supported by a growing population and diverse economy. The CSIRO-led Darwin Living Lab resides within the Darwin City Deal, and seeks to foster improvements in Darwin's liveability, sustainability and resilience. **This e-book provides a series of important stories and conversation starters for Darwinites (Figure 1).**

01 Urban Heat Island – there are a number of initiatives underway to reduce temperature and improve the liveability of Darwin – what works and what doesn't?

02 Healthy Outdoor Environments are an important part of liveability – how do the people of Darwin interact with the outdoor environment and how does that outdoor environment return benefit?

03 Water is a Key Resource (for Cooling) – how much water is needed for a cool and liveable Darwin, and how much pressure does that put on a sustainable and resilient water supply for Darwin?

04 Sustainability: Towards Net-Zero – what is the situation, and how can Darwin, with all its challenges, adapt to a net-zero future?

05 Indoor Liveability – how can improvements in tropical design lead to more liveable and sustainable indoor environments?

Figure 1. Important stories and conversation starters for Darwin.

1 Kavaarpuo, G et al. (2022). Darwin: Towards the sustainability of the Larrikin of Australian capital cities. Cities, 120, 103457. https://doi.org/https://doi.org/10.1016/j.cities.2021.103457
2 Lea T (2020) Darwin, NewSouth Books, Sydney.
3 Carment D (2019) Australia's northern capital: a short history of Darwin. Darwin. Historical Society of the Northern Territory Inc.
4 Dale et al. (2014) From Myth to Reality: New Pathways for Northern Development, Northern Development Summit, Townsville.
5 Coates L et al. (2014) Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. Environmental Science and Policy, 42, 33–44.

With consideration of the drivers, pressures, state, impact and response – the DPSIR framework (Figure 2) was used to identify cause-effect relationships within each story (or sub-system). For each of these sub-systems, we explore past, present and future Darwin with maps, data and links to further information to understand how the components of the city are changing. The systems approach brings focus to interrelated challenges (Figure 3) to assist the city, its people and practitioners to consider a wider set of variables and potential impacts when developing strategies and policies, and making decisions.

Before delving into each story, the remainder of this section provides a snapshot of the Darwin context and a summary of its interrelated challenges.

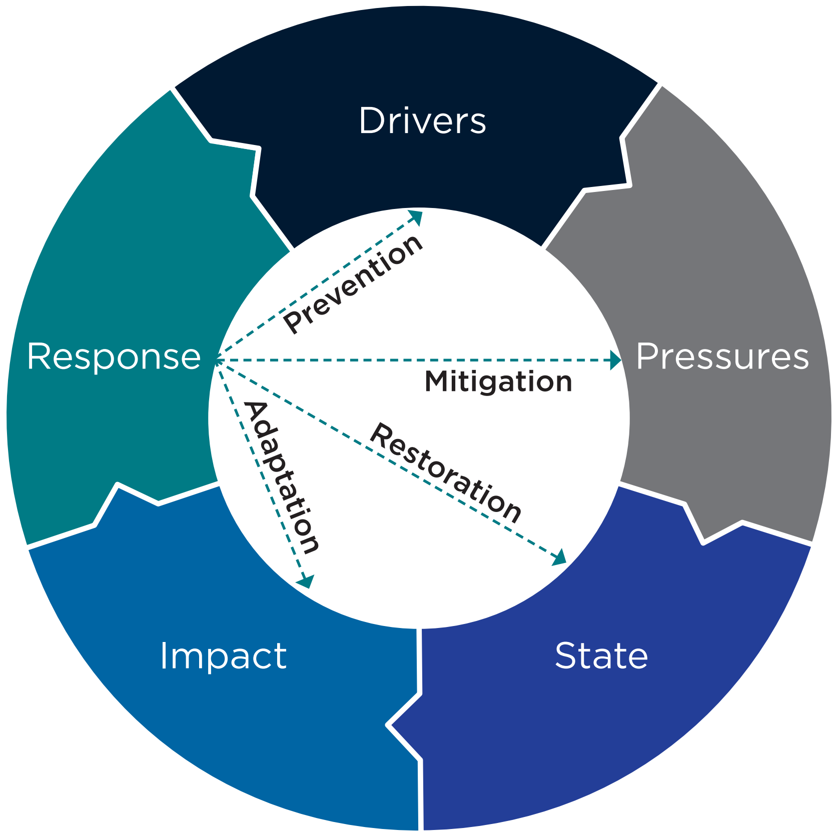


Figure 2. DPSIR framework for the evaluation of cause–effect relationships and strategic and policy responses.

Drivers list (social needs)

Health

- Thermal comfort (dealing with heat and humidity)
- Active lifestyle despite hot outdoors
- Quality drinking water
- Avoid biting insects (mosquitoes) and dangerous animals
- Good air quality

Liveability

- Affordable cost of living
- Infrastructure services delivered affordably

Culture

- Maintaining the 'Darwin' lifestyle
- Larrakia (valuing traditional knowledge)
- Boating and shooting
- Outdoor 'tropical' lifestyle
- Expectations of green lawns all year

Security

- Darwin important for national security
- Personal safety at night
- Public transport safety

Economic growth

- Jobs and financial security
- A bigger population
- Urban land expansion

Pressures list

- Population growth (material, energy and water requirements; waste generation)
- Defence aspirations and expansion
- Land use and urbanisation
- Increased compact development (reduced green space in lots) and competition for green space (pressure on biodiversity)
- Cultural expectation for large homes
- Warming temperatures (climate and urban heat)
- Increased water demand to cool and green
- High water demand in tropical climate (high per capita use)
- Wet-dry seasonal variations
- Climate: seasonal change (dry season shrinking)
- Burning of surrounding savanna landscape
- Green spaces becoming more expensive to maintain compared to other land uses (i.e. concrete)
- Loss of canopy (shade) during cyclones
- Energy demand for air-conditioning to maintain thermal comfort
- Rising household energy costs (cost of living)
- Night-time use of outdoors limited (due to safety concerns)
- Night-time lighting and energy (cost and emissions)
- Isolated (oil for transport, high infrastructure costs)

Figure 3. The 'Darwin system': drivers and pressures have been identified within the five important stories for Darwin. Drivers represent the core social needs of Darwinites. Pressures create challenges on the supply or access to the needs.

Darwin – growing the capital of the north

Darwin is the largest city along Australia's northern coastline. Greater Darwin – comprised of Darwin City, Palmerston and Litchfield local government areas (LGAs) – has a resident population of 139,902 people, with the majority (80,530) of people living in the City of Darwin LGA.[6]

The Our North, Our Future: White Paper on Developing Northern Australia and Northern Australia Action Plan 2024–2029 aspires to achieve economic expansion in the north of Australia, and lay the foundations for accelerated population growth.

Figure 4 depicts the change in Darwin's population between 1971 and 2021. During this time Darwin's population increased by nearly fourfold, making it the fastest growing Australian capital city over this period. However, the population growth rate fluctuated over this period. It declined 34% in the aftermath of tropical Cyclone Tracy in 1974 and then quickly rebounded to pre-cyclone levels with the Darwin Reconstruction Commission rebuilding the city within 3 years. Since the 2000s, population growth has been driven by resource booms, particularly liquefied natural gas (LNG) processing plants. In recent years, the end of the construction phase of these mega-projects has seen Darwin's population growth level off.

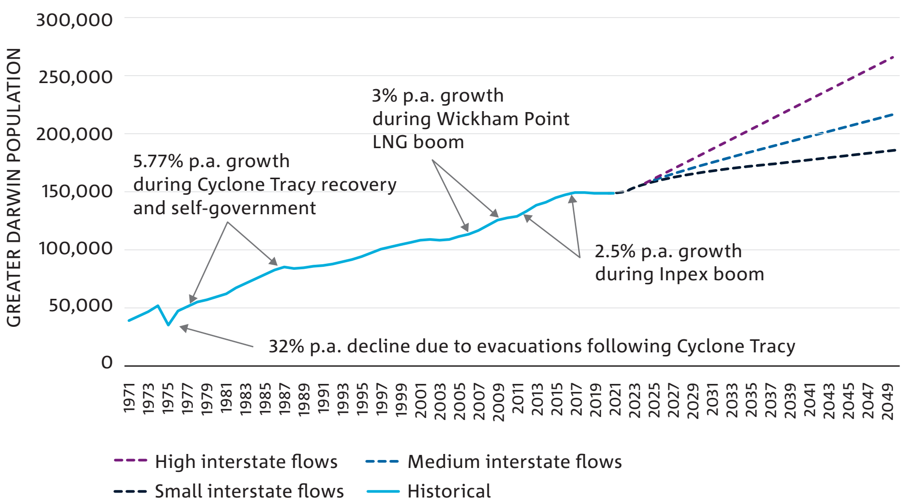


Figure 4. Greater Darwin population change (1971–2023) and projected population growth to 2050. Source: Australian Bureau of Statistics (2022)[7]

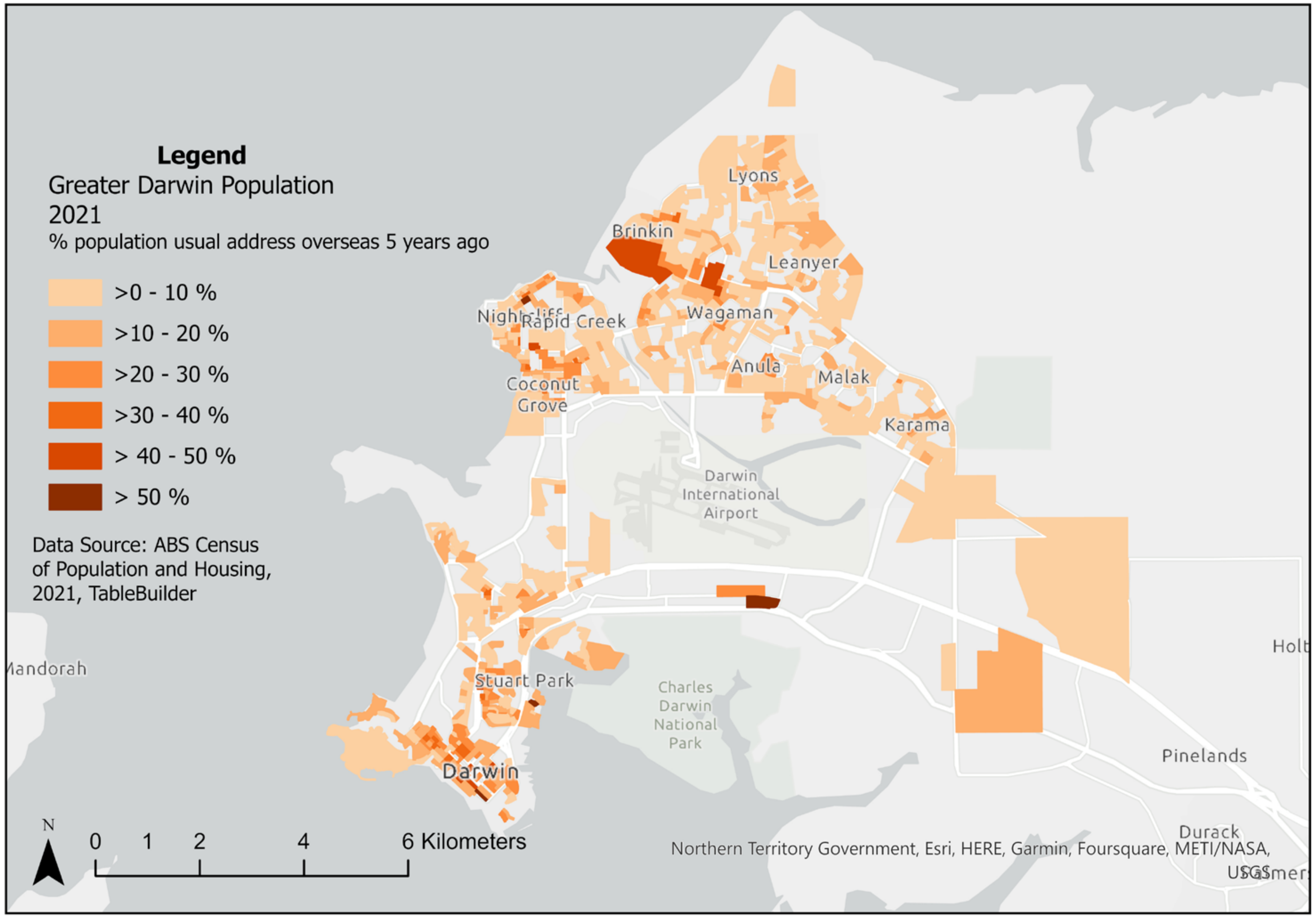


Figure 5. Percentage of the Darwin population in 2021 whose usual address 5 years ago was overseas. Source: ABS (2022).

Darwin's population is projected to grow over the coming decades, with Australian Bureau of Statistics (ABS) projections for the population to reach between 186,393 and 267,061 by 2050, depending on the level of interstate flows. The Northern Territory (NT) population has historically had net negative migration to other states, with population growth driven by net overseas migration and natural fertility.[8]

Darwin's population has been described in the past as transient,[9] a trend that continues. At the time of the 2021 ABS census, around 30% of Darwin's population had moved from interstate or overseas within the past 5 years.

During the intercensal period, 7,497 people moved from overseas to Darwin, and 12,561 from interstate. Over the same period, 17,605 people migrated interstate from Darwin, with the most significant migration losses to Queensland. New South Wales was the only state where Darwin had a net migration gain between 2016 and 2021, with 137 more arrivals than departures (+3,049/–2,912).

The suburbs hosting the greatest percentage increase of overseas arrivals are parts of Winnellie, Darwin City, Nightcliff, Stuart Park, Brinkin, Wanguri and Wagaman (Figure 5).

6 Australian Bureau of Statistics (2021) ABS Census of Population and Housing
7 Australian Bureau of Statistics (2022) 50 years of capital city population change: An overview of Australia's capital city population change between 1971 and 2021
8 Australian Bureau of Statistics (2019) 3105.0.65.001 Australian historical population statistics.
9 Carson et al. (2010) Whose City is this?: a thinking guide to Darwin, Charles Darwin University Press.

Figure 6 shows the percentage of the population that lived in a different address since the previous census in 2016. This captures both the new residents in Darwin and those who may have moved within Darwin itself. This shows that all parts of Greater Darwin – both newer and older suburbs – experience turnover.

Taylor and Carson (2017)[10] reviewed population growth and challenges to retaining population in the Territory, finding there are many factors for population movement (in and out). Work is the main factor for leaving. Also, there are many people at life transition points, such as retirees from full-time work, who decide to leave the Territory because of cost-of-living pressures or to be closer to family or friends. Climate is another cited factor, with 15% of seniors seeking to leave the Territory due to the hot climate.[11] Taylor and Carson say that "On the whole … it is difficult to imagine the net outcome for migration in the Territory resulting from climate change will be positive".

Defence presence in Darwin is another cause of high population turnover and growth. In the past, Defence needs have led to rapid expansion, and future rapid expansion is plausible noting strengthening national security and accelerated preparedness in Australia's north.[12] DefenceNT is the primary office for engaging on matters of defence and national security, and works to ensure NT policy aligns with Commonwealth Defence strategic objectives. Defence Housing Australia procures land to develop for Defence housing private development, such as that of Muirhead and future development at Lee Point. All developments undertaken in the NT are done through the Planning Act and Planning Regulations.

There have been calls for diversification of the economy in the NT, to avoid reliance on resource sector mega-projects, which have been the main driver of boom-bust cycles. Policy for this diversification is currently centred on growing tourism, growing the education sector and attracting industry to explore possibilities within the NT. Operation Rebound / Jobs First put steps in place for a $40 billion economy by 2030, and to set the conditions to get new investment into the Territory as quickly as possible. This set the ambition to boost the NT population beyond 300,000.

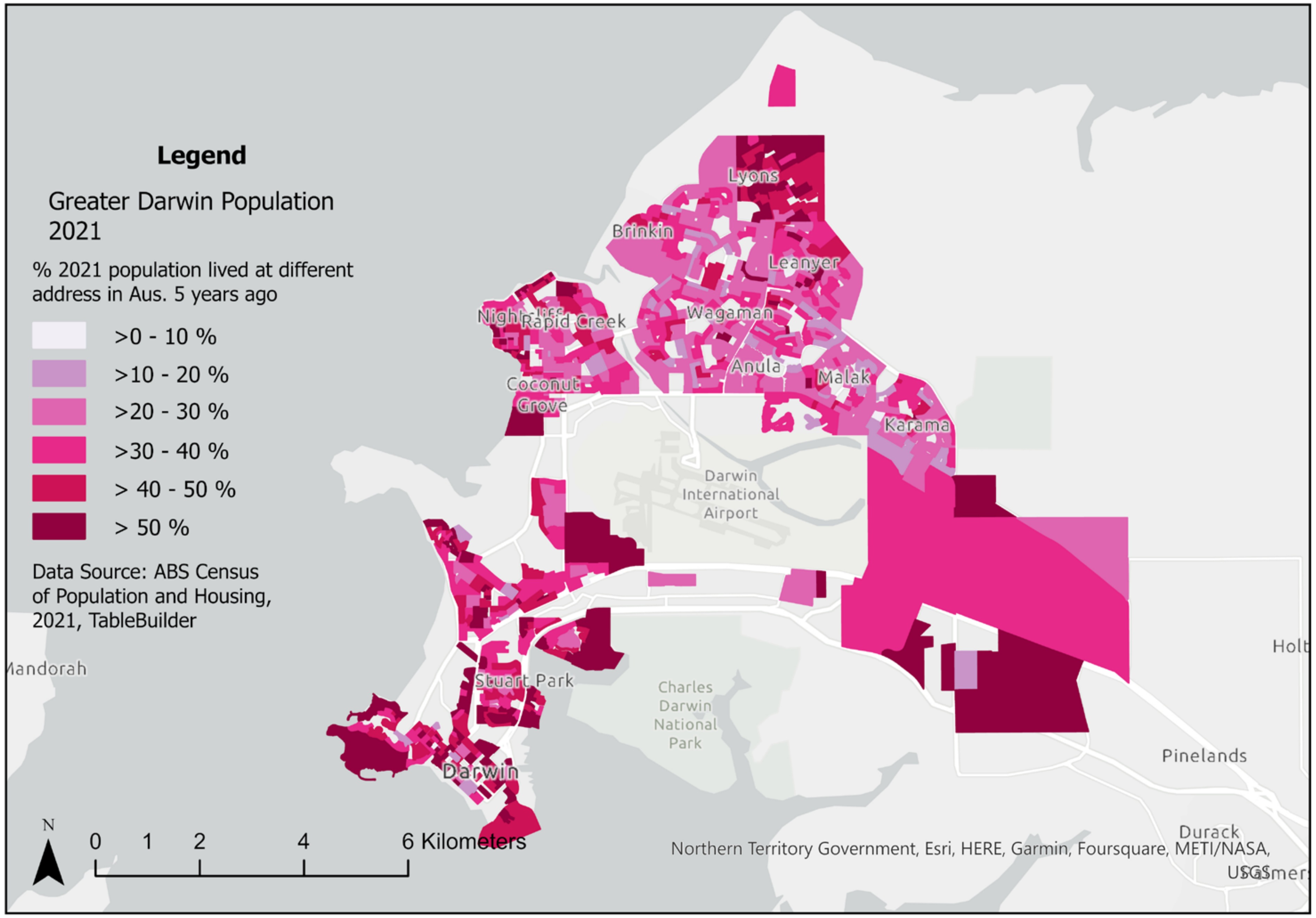


Figure 6. Percentage of the Darwin population in 2021 who lived at a different Australian address 5 years ago. Source: ABS (2022).

10 Taylor A and Carson D (2017) Synthesising Northern Territory Population Research: Charles Darwin University Northern Institute.

11 COTA NT 2018 Senior's survey.

12 National Defence: Defence Strategic Review 2023

What would Darwin look like with a greater population?

Strategies for increased population have been explored by the NT Planning Commission, with the last Darwin Regional Land Use Plan released in 2015. Following the development of Muirhead, Lee Point and Berrimah, there will be limited unconstrained land in Darwin for urban development[13] (Figure 7). This will result in the Darwin LGA concentrating greater effort on infill and population densification. The majority of new urban development will occur in Palmerston and Litchfield LGAs. Industrial expansion at Middle Arm and subregional plans developed for Holtze to Elizabeth River promise to expand development around Palmerston and connect to Weddell, which has been cited as the next satellite city to be established in the Greater Darwin region.

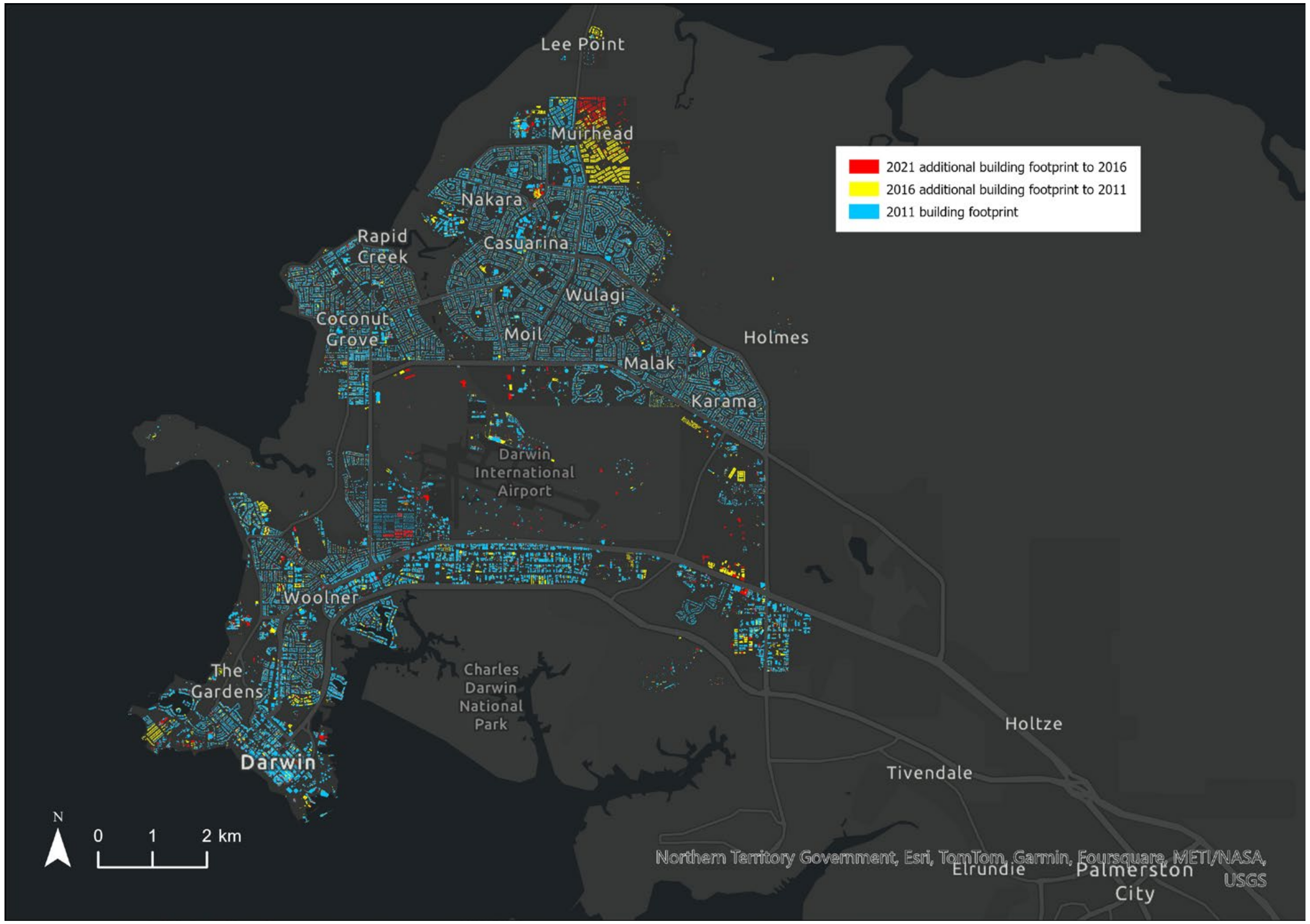


Figure 7. Building footprints in Darwin in 2011, and additional building footprints added by 2016 and 2021.

Bolleter[14] explored scenarios that would see Darwin increase to a population of 1 million. The study estimated developable land required would greatly exceed available non-constrained land within a 50 km radius, and if waterlogged landscapes are respected, Darwin would sprawl in a long corridor to Humpty Doo and Acacia Hills, leading to long commutes and inequitable access to coast, jobs and cultural amenity (Figure 8). Population expansion along transport corridors would likely lead to wide strips of development that potentially block movement patterns for key wildlife species. As a mechanism to improve liveability and avoid urban sprawl, some authors have proposed that the Darwin International Airport should be relocated to the south-east, allowing for increased urbanisation on the existing airport site, and improved amenity and connectivity between Darwin's suburbs.[15] The Darwin Regional Transport Strategy (2018) suggests that road transport will continue to dominate to 2050, with light rail a potential future option to assist mass transit in the longer term (beyond 2050).

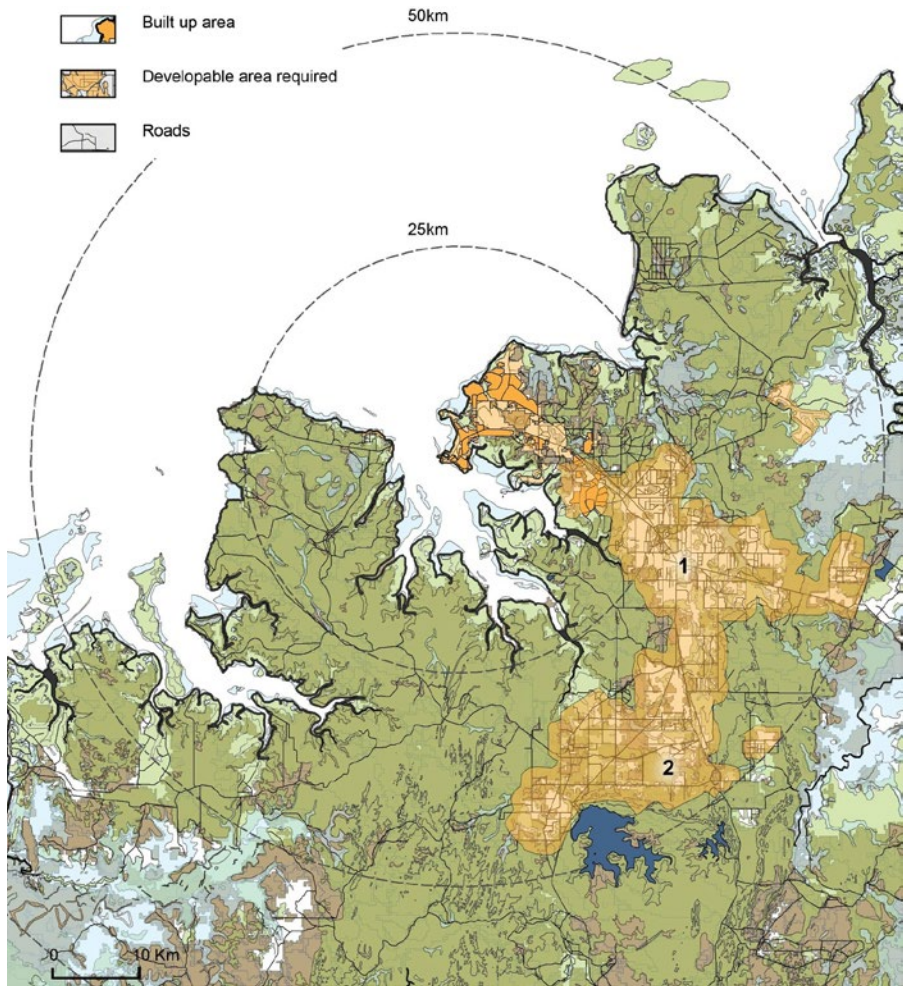


Figure 8. A growth scenario for Darwin to achieve a population of 1 million. Bolleter JA (2018) The consequences of three urbanisation scenarios for northern Australia, Australian Planner. Published 4 June 2019. Reprinted by permission of Taylor & Francis Ltd.).

13 NT Planning Commission https://planningcommission.nt.gov.au/projects/lslup/faq

14 Bolleter JA (2018) The consequences of three urbanisation scenarios for northern Australia, Australian Planner, 55, 103-125. https://doi.org/10.1080/07293682.2019.1620302

15 Weller R and Bolleter J (2013) Made in Australia: the future of Australian cities. UWA Publishing.

Darwinites

The people of Darwin – 'Darwinites' – have been described as portraying a touch of Larrikin[16] and being a resilient[17] people. Many just want a quiet life and to be left alone. When it comes to heat, Darwinites have been referred to as 'thermal mavericks' in academic studies,[18] which relates to segments of the population that live without extensive cooling, and express comfort at more extreme temperatures than predicted as acceptable by international models for thermal comfort. Darwin Living Lab research[19] has suggested Darwinites keep cool by being more active at dawn and dusk, and that beer, less clothing and water are useful. Some would like clothes such as sarongs and shorts to be more acceptable as business attire, and some would like a siesta, and to work, play and exercise into the night (assuming increased lighting would make it safer to be out at night).

Darwin's Indigenous presence is both a historic and a contemporary force.[20] Darwin has the highest proportion of Aboriginal and Torres Strait Islander people relative to its population size (10.4%) compared to other Australian capital cities.[21] Darwin is also a central hub, hosting 60% of the NT's population.

Like other Australian cities, Darwin's population has a diverse multicultural composition.[22] Gold discovery at Pine Creek in the 1880s attracted immigrants from China and Singapore. Steady growth in the pearling industry attracted Indonesians and other Islanders. Commonwealth interests ramped up during the 1930s, prioritising Darwin as a northern military instalment. Following World War II, Darwin continued to serve as a military and administrative centre, seeing increased immigration from Europe. The ABS 2021 census showed that Greek (at 3.3%) was the highest non-English language spoken at home.

What draws people to Darwin?[23] Employment opportunities are a key part,[24] but being in the outdoors and experiencing nature and the seasons are also key attractors and reasons for staying. Attending festivals and markets, watching storms and lightning, hearing the rumbling of thunder and chirping of birdlife, getting out to waterfalls and peaceful camping spots, and appreciating wildflowers and flora and fauna. This love of nature reinforces the need to have the right equipment, and a 4WD or SUV, to travel large distances and to explore the vast natural landscapes. Furthermore, fishing is a massive drawcard and part of the Darwin and Territory lifestyle. This highly valued recreation reinforces a strong hunting and fishing lobby that needs to be considered when it comes to local decision-making. Fishing for a barra, jewfish, bream, coral trout, golden snapper or mudcrab will also require a boat and a nice-sized shed to fit the boat and all the associated equipment.[20] The relative isolation means that shipping in goods often costs more, creating both a financial and environmental (CO_2 emissions) penalty – 'gammon', but that is just how it is.

Changing seasons in Darwin

Co-authored by Josephine Brown, University of Melbourne

Northern Australia, including Darwin, has a changing climate and future conditions will not be the same as the past. In the period 1950–2022, average maximum and minimum temperatures in Darwin increased (Figure 9), with the average maximum temperature increasing by 0.9°C. Darwin has had, and can continue to expect, an increase in the average number of days per year above 35°C, with an increase from 11 days (1981–2010) to a projected 43 days by 2030 and 111–265 days by 2090.[25] More recent projections suggest up to 317 days equal to or above 35°C in any one year by 2090.[26] In 2019, there were 45 days above 35°C, including a record 11 days in a row, already exceeding projections for 2030. With warming temperatures and high humidity seasons, maintaining liveability and Darwin's cherished outdoor tropical lifestyle is a significant challenge. The health impacts are of increasing concern as heat extremes are linked with higher rates of mortality and hospital admissions and decreased rates of productivity and exercise.[27]

Since 1970, average rainfall has been increasing overall across the north-west of Australia, including Darwin. Scientists continue their efforts to figure out exactly why this is. There has also been a trend towards an earlier start to the wet season and a significant increase of early 'monsoon bursts'. This, combined with later retreat dates, has seen the average length of the wet season increase by 3.4 days per decade since 1900. This means that Darwin has lost 34 days of its annual dry season over the past 100 years.

Darwin's monsoonal rainfall is influenced by several factors. The monsoon occurs when the easterly trade winds reverse and become moisture-ladened westerlies. This usually happens around 25 December and persists through to March–April. The onset of the monsoon typically occurs later in El Niño years, and earlier in La Niña years where there is also above average rainfall. Another major influence is the Madden-Julian Oscillation (MJO), an eastward moving pulse of equatorial moisture-ladened cloud, mainly originating from the Indian Ocean, which comes into effect every 30 to 60 days and can alter wet-dry patterns for up to a month at a time. MJO is often a trigger for the onset of the monsoon, and can also cause monsoon bursts within the dry season and weaken or reverse the monsoon. Other factors include the east–west see-sawing of temperatures in the Indian Ocean (Indian Ocean Dipole) and tropical cyclones, which can dump up to 30% of annual rainfall.

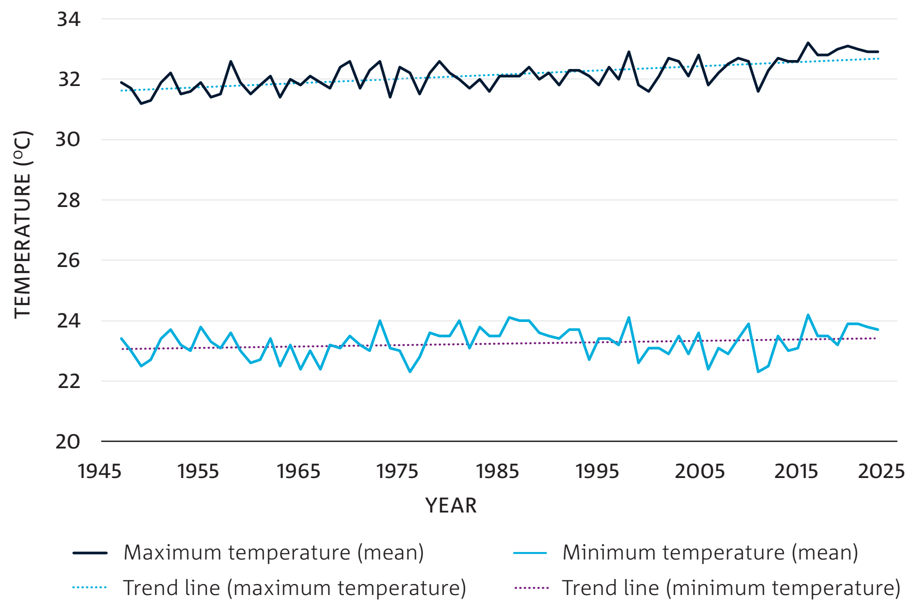


Figure 9. Maximum temperature (annual mean) as recorded at Darwin airport. Data source: http://www.bom.gov.au/climate/data/index.shtml

16 Kavaarpuo, G et al. (2022). Darwin: Towards the sustainability of the Larrikin of Australian capital cities. Cities, 120, 103457. https://doi.org/10.1016/j.cities.2021.103457
17 Dale et al. (2014) From Myth to Reality: New Pathways for Northern Development, Northern Development Summit, Townsville.
18 Daniel et al. (2014) Learning from the thermal mavericks in Australia: comfort studies in Melbourne and Darwin, Architectural Science Review. http://dx.doi.org/10.1080/00038628.2014.976537
19 https://research.csiro.au/darwinlivinglab/wp-content/uploads/sites/278/2021/01/Thriving-Cool-Darwin-A-Day-in-the-Life-final.pdf
20 Lea T (2020) Darwin, NewSouth Books, Sydney.
21 Australian Bureau of Statistics (2021) ABS Census of Population and Housing
22 Lobo (2021) Living on the edge: precarity and freedom in Darwin, Australia, Journal of Ethnic and Migration Studies, 47:20, 4615–4630 https://doi.org/10.1080/1369183X.2020.1732585
23 Explore the 'I Love Darwin' Facebook Group https://www.facebook.com/groups/668711854761713/
24 Taylor A and Carson D (2017) Synthesising Northern Territory population research: a report to the Northern Territory Department of the Chief Minister. Charles Darwin University. Northern Institute.
25 Moise, A. et al. 2015, Monsoonal North Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekström, M. et al., CSIRO and Bureau of Meteorology, Australia
26 NESP Earth Systems and Climate Change Hub. 2020. Climate change in the Northern Territory: state of the science and climate change impacts. NESP ESCC Hub, Melbourne.
27 Bhatta et al. (2023) Examining the heat health burden in Australia: a rapid review https://doi.org/10.3390/cli11120246

The water situation

Darwin's urban demand for water often exceeds the sustainable yields from surface water catchments.[28] With population and economic growth likely to exacerbate these challenges, and the potential impacts of climate change on increased inter-annual variability in wet season inflows to surface water catchments, it is important to ensure that Darwin has a sustainable water future.

Darwin households use twice the amount of water compared to most Australian capital cities,[29] with most of this water being used to irrigate gardens. This is in part influenced by the wet-dry tropical climate, where little rainfall over the dry season means there is the need for irrigation to maintain green spaces to meet the expectation of many people that a 'tropical city' should be green all year.

Despite high humidity at times of the year, water is also important for cooling. Storms bring rain and cold air down to the surface, cooling paths and roads. Pools, waterholes, sprinklers and misters help to reduce heat. Analysis of land surface temperatures in Darwin shows that areas that retain soil moisture over the dry season are relatively cooler. The use of shade trees and irrigated green space reduces temperatures in urban landscapes through shading and cooling via evapotranspiration.

For the Larrakia people, lore and spirituality are intertwined with connection to land and water. Water remains central to the lives and culture of the traditional owners today, with many sites of cultural significance being water related.

Darwin's low-lying terrain, including mangrove wetlands and swamps, reduces the area of land that can be developed, and gives rise to potential issues with things that bite, such as mosquitoes and potentially crocodiles.

Urban development creates pressures

Along with population growth comes the need for city expansion, and there is a global shift towards urbanisation (more people living in cities). Land use planning has changed over time and is shifting to smaller residential lots driven by sustainability objectives that seek higher urban density, compact living and decreased travel distances. This is reinforced by property market pressures that attempt to deliver affordable housing while preserving financial yield for developers. The average size of a home in Australia is towards the largest in the world,[30] which means that homes generally push out to the edges of the block and limit room for green space or to plant shade trees,[31] and there is less space for breeze to flow through the landscape.[32] This trend of increasing the percentage of hard infrastructure is likely to increase the urban heat island. Historically, most Darwin homes were on large blocks with a separate house. This layout is likely to have a bigger garden area, and though require more water, provide local mitigation of heat and support forms of biodiversity. While more medium-density and high-density developments are occurring, just under 50% of Darwin's households remain separate dwellings.

A more compact Darwin with increased infill would likely bring the average person closer to services, deliver a more effective public transport system, and encourage active transport – such as walking, cycling and using e-scooters (assuming people feel safe to use these modes of transport). Darwin's flat terrain is also advantageous for active transport. The planning challenge for shifting to more compact cities is to maintain useable green space that reinforces a healthy outdoor environment that can provide liveability and passive cooling. Passive cooling via greening, shade and encouraging breezes to flow has been demonstrated to reduce the urban heat island effect and offset energy demand for cooling indoor environments. As heat increases in Darwin the response is not as simple as turning up the air-conditioner, which would not only add to CO_2 emissions and reinforce a warming climate, but would increase energy costs and cause financial hardship or health risks for those unable to afford to use air-conditioning.

It is important to ensure that building design and energy systems are suited to Darwin's unique tropical climate and that there is a shift to renewable energy. Homeowners may choose to invest in solar energy generation and energy storage, and this may flow through to increased uptake of electric vehicles (EVs) and personalised e-scooters and e-bikes.

The overall demand for energy across a warming and growing city is expected to be met increasingly with renewable energy – wind and solar – supplemented by batteries, thermal storage and gas. CO_2 offset schemes will involve planting more biomass (e.g. trees and shrubs) in rural areas, which is likely to lead to heightened dry season burning, adding to Darwin's health risks associated with poor air quality.[33]

These are just some of the interrelated aspects of creating a liveable, sustainable and resilient Darwin.

The following sections present the five important stories and conversations for Darwin:

- **01** Urban Heat Island
- **02** Healthy Outdoor Environments
- **03** Water is a Key Resource (for Cooling)
- **04** Sustainability: Towards Net-Zero
- **05** Indoor Liveability

28 Power and Water Corporation, Darwin water supply.
29 Bureau of Meterology, Urban National Performance Report
30 https://www.commbank.com.au/articles/newsroom/2020/11/commsec-home-size-trends-report.html
31 Hall (2010) The Life and Death of the Australian Backyard. CSIRO Publishing. ISBN: 9780643098169.
32 Law et al. (2021) Design for liveability in tropical Australia. Leading from the North: Rethinking Northern Australia Development. https://doi.org/10.22459/LN.2021.20
33 Jones et al. (2022) Smoke pollution must be part of the savanna fire management equation: a case study from Darwin, Australia. https://doi.org/10.1007/s13280-022-01745-9

01 Urban Heat Island

Extreme heat can have profound adverse effects on the health of individuals. It is not only the temperature during the day, but it is also important to get a good night's sleep. Heat can be exacerbated in urban areas in an effect known as the urban heat island,[34] where materials such as asphalt, concrete and bricks absorb and re-emit the sun's heat more than natural landscapes.

The daytime ambient temperature for Darwin's central business district (CBD) was measured by the University of New South Wales (UNSW) in March 2017 as being 2–3°C hotter than Darwin airport. However, the effect of the urban heat island is typically felt the greatest during the night[35] (Figure 10). City of Darwin Environmental Sensor Network data confirm average daily differences in ambient temperature between the CBD (and other parts of the city) and the airport (Winnellie) to be up to 2°C during the day and up to 3°C just before sunrise.

On average, the hottest time of the day occurs between midday and 2 pm. Over a diurnal cycle (i.e. day and night), humidity has an inverse relationship with temperature. This means that even when temperatures decrease, humidity increases, and results in maintained levels of high heat index[38] for larger parts of the day. Seasonal effects (Figure 10) show the heat index for Darwin as more severe during the wet season (Oct–Apr).

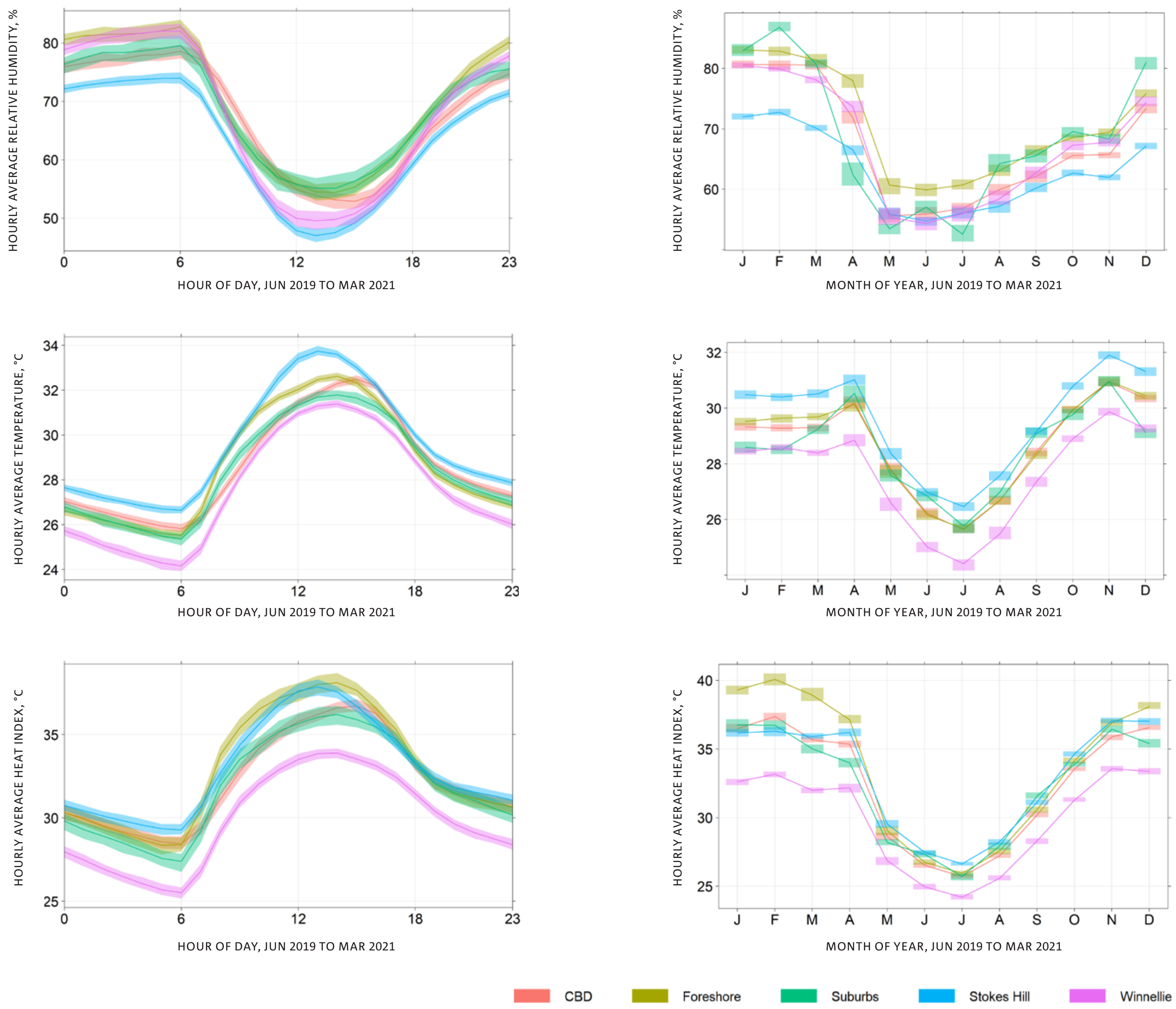


Figure 10. Diurnal and seasonal variations in temperature, relative humidity and heat index are determined from the sensor data and grouped by location type (CBD, suburbs and foreshore). City of Darwin sensor data are presented alongside data from Bureau of Meteorology[36] and NT Environment Protection Authority[37] monitoring stations at Winnellie (Darwin airport) and Stokes Hill (CBD). For further information, refer to the Darwin Living Lab report.

34 Oke, TR (1982) The energetic basis of the urban heat island. https://doi.org/10.1002/qj.49710845502

35 Arnfield AJ (2003) Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. https://doi.org/10.1002/joc.859

36 http://www.bom.gov.au/products/IDD60901/IDD60901.94120.shtml

37 Envista – Air Resources Manager (ntepa.webhop.net)

38 Nairn et al. (2002) The impact of humidity on Australia's operational heatwave services. https://doi.org/10.1016/j.cliser.2022.100315

Heat distribution across Greater Darwin – land surface temperature

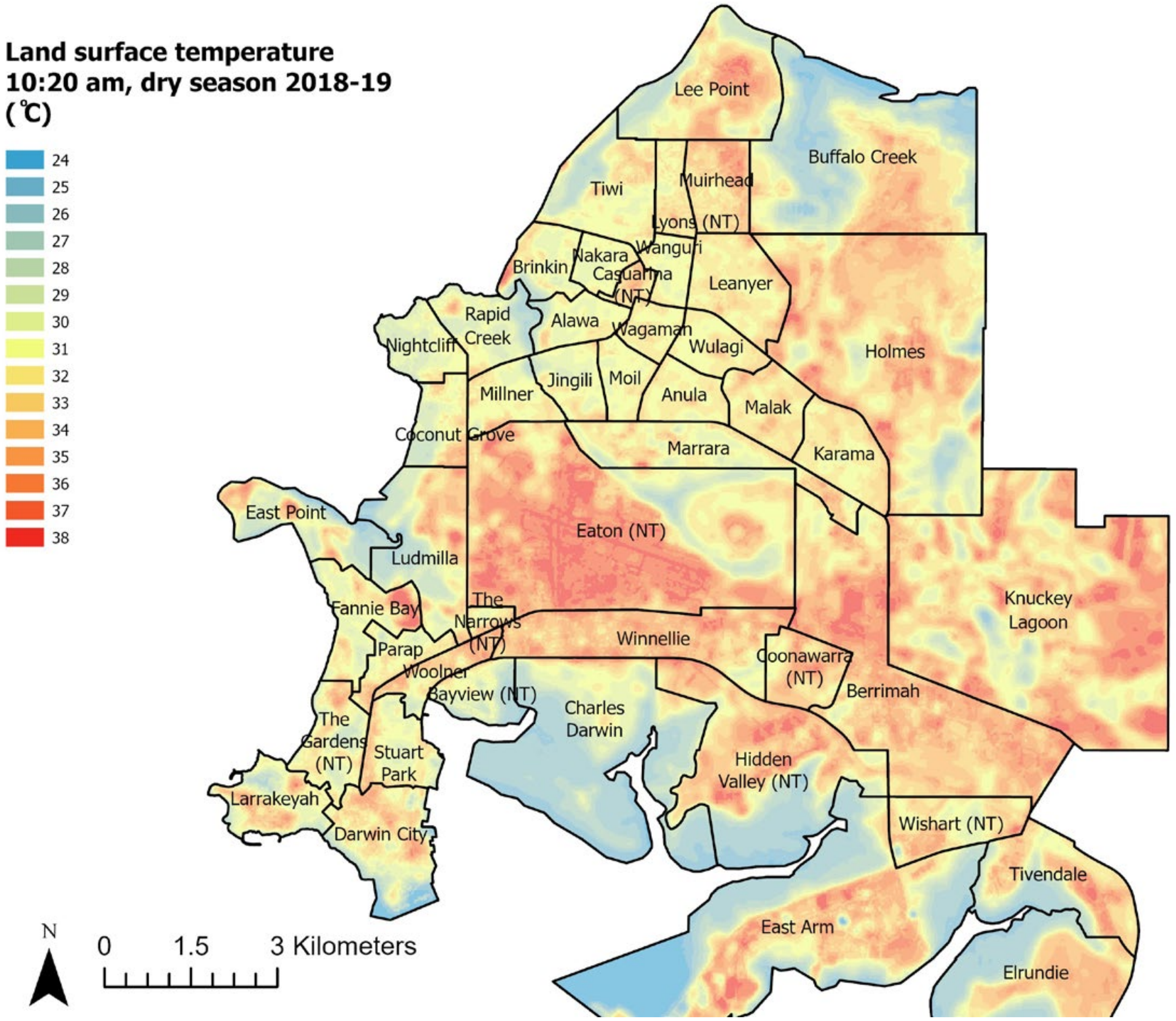


Figure 11. Land surface temperature mapping allows the identification of hotter and cooler features across the landscape and built environment. Data were generated from six clear-day Landsat 8 satellite images during the 2018 and 2019 dry seasons at 10:20 am to provide land surface temperature images with a 30 m resolution. Cooler areas are associated with water, trees, irrigated grass and proximity to coast. Hotter areas include paving and bitumen, rooftops, bare ground with fewer trees and unirrigated dry grass. These data have been integrated with demographic and socioeconomic data (see Figure 24) to highlight areas where more residents may be exposed to higher temperatures, have a higher risk of heat-related illness, and have fewer economic resources to respond.[39]

Lee Point Road, Muirhead – shared path

39 Meyers et al. (2020) Mapping land surface temperature and heat-health vulnerability in Darwin, CSIRO

Darwin City Deal investments

The Darwin City Deal has invested in a number of heat mitigation activities. Feeling Cooler in Darwin, a co-developed heat mitigation and adaptation strategy, has 30 actions to progress Darwin to be a cooler and more liveable city. The Cavenagh Street redevelopment is showcased in the strategy as an example of a street-cooling project.

Cooling Cavenagh Street

A UNSW study conducted in 2017–18 for the NT Government identified a number of 'hot spots' within the City of Darwin. Cavenagh Street was one of the hottest and is now a testing ground for heat mitigation strategies for Darwin. Actions include tree planting (29 native trees), a 55 m shade structure and additional road intersection shades, CoolSeal heat reflective road coating at Knuckey Street intersection and cool pavements adjacent to the main shade structure. Monitoring by the Darwin Living Lab and UNSW continue. A Darwin Living Lab project led by Charles Darwin University has built capacity to collect data at precinct scale using uncrewed aerial vehicles (UAVs, or drones), which has provided insights through comparison of land surface temperatures (Figure 12).

Observations in Cavenagh Street have shown shaded road surfaces to have decreased temperatures by up to 21.2°C in comparison to sun-exposed surfaces. Surface temperature reductions of 3.5°C have been measured for reflective road surfaces in comparison to conventional road surfaces. Planted in late 2018, the canopy when looking down on the vines from above the Cavenagh Street shade structure, are comparable to those of large street trees planted in May 2019, showing that alternative or engineered structures have the capacity to provide shade quicker than trees (which take years for the canopy to develop). Canopy density (usually measured as leaf area index) is another important factor in determining shade performance and surface temperature reduction.[40]

Monitoring by UNSW[41] has shown ambient temperatures under the shade to be about 0.5°C lower than outside of the shade during the day, and to have minimal difference at night-time.

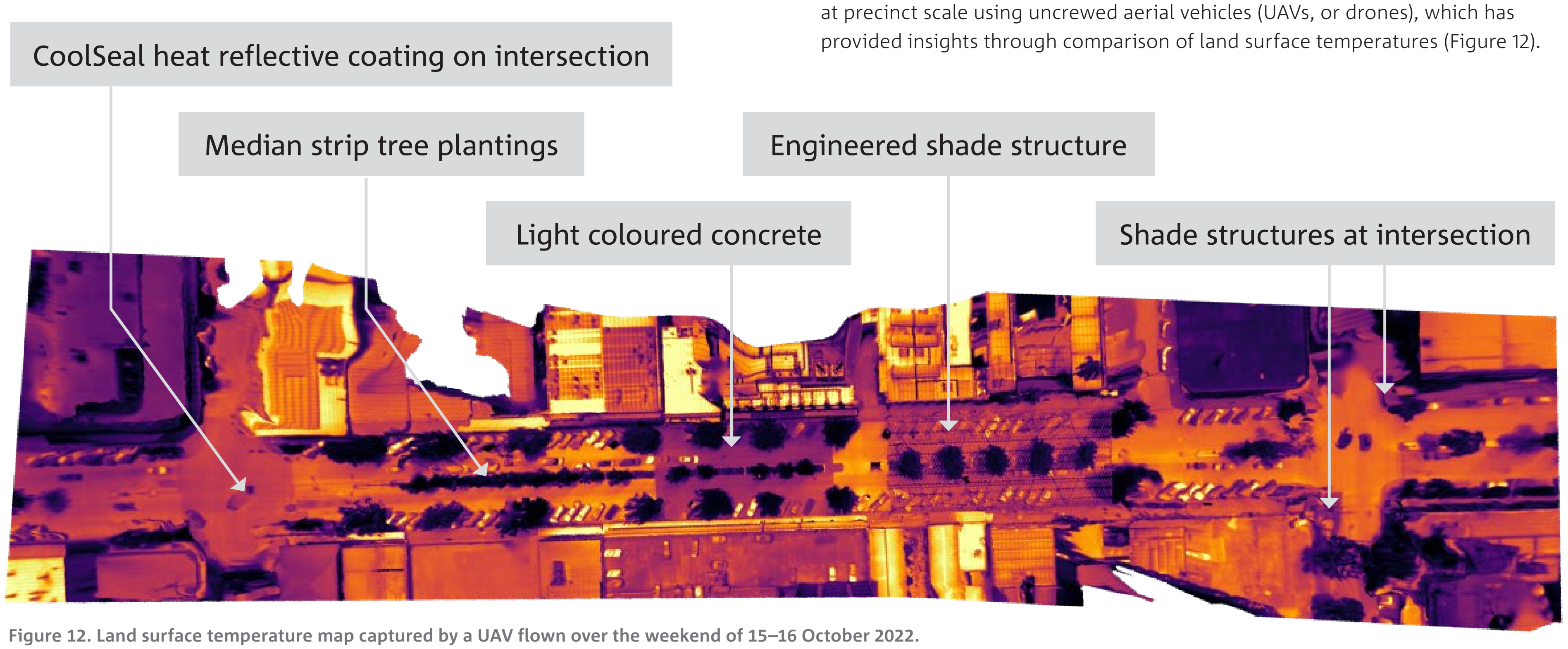


Figure 12. Land surface temperature map captured by a UAV flown over the weekend of 15–16 October 2022. Courtesy of Charles Darwin University. Colour scale: purple = cool, yellow = hot.

State Square

Figure 13 depicts a thermal image of the State Square precinct in comparison to a true-colour image. This highlights that hotter surface temperatures are associated with unshaded bitumen car park, and areas of bare ground and wood mulch. The cooler surfaces are associated with tree canopy and areas of healthy grass.

Thermal imaging (Figure 14) before and after the completion of State Square revitalisation Stage 2 shows an increased area with cooler surface temperatures after the removal of heat-retaining asphalt (50–53°C as measured on 23/3/2017) and replacement with irrigated grass (surface temperature of 42–43°C measured on 13/12/2022). The new asphalt outside of Parliament House measured on 13/12/2022 had a surface temperature that was 17.6°C hotter than nearby irrigated grass. As newly planted trees within State Square establish themselves this will provide additional heat mitigation benefits through evapotranspiration and increased shade.

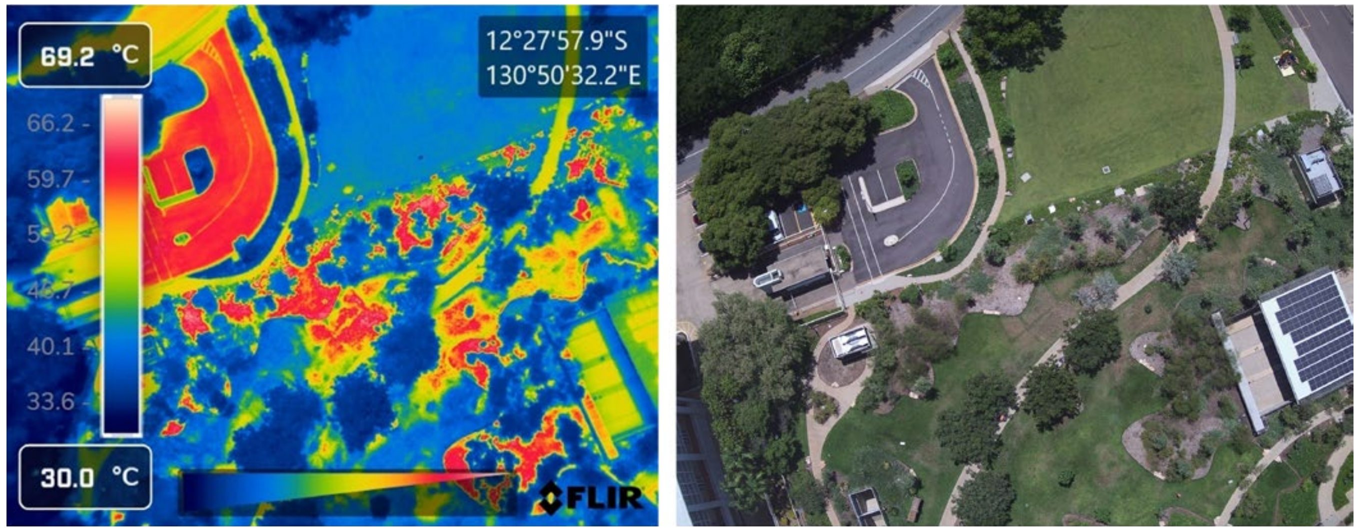


Figure 13. Thermal image showing land surface temperature in comparison to true-colour image – State Square revitalised green space (13 December 2022)

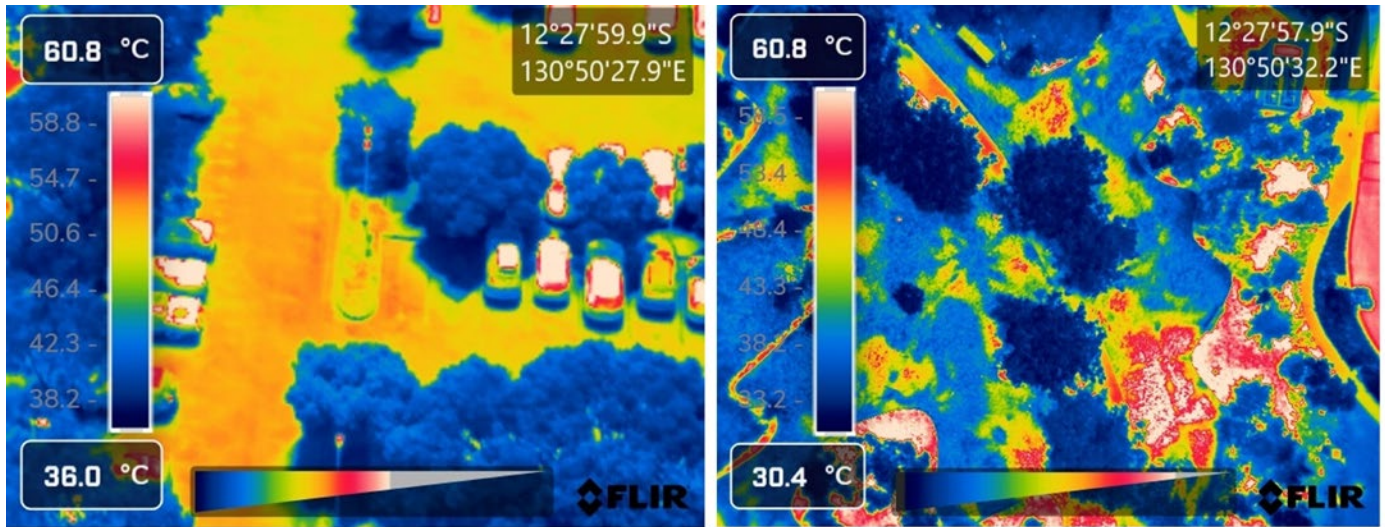


Figure 14. Left: Thermal image of '90-bay carpark', 23 March 2017, 12:15 pm. Right: Thermal image of '90-bay carpark' revisited after State Square revitalisation, 13 December 2022, 1:10 pm.

40 Hardin and Jensen (2007) The effect of urban leaf area on summertime urban surface kinetic temperatures. https://doi.org/10.1016/j.ufug.2007.01.005

41 Haddad et al. (2023) Measuring the performance of urban heat mitigation implemented in Darwin, a wet-dry tropical city. 11th International Conference on Urban Climate, Sydney.

City scale changes

CSIRO Urban Monitor™ enables city scale data to be extracted from digital aerial photography. With a resolution of 20 cm, various digital layers or maps have been generated over Greater Darwin with a focus on changes between the census years 2011, 2016 and 2021. These data support work towards developing a digital twin for Darwin. Urban Monitor datasets of Greater Darwin land surface cover and change can be downloaded and includes:

- surface reflectance (mosaic)
- average surface reflectance
- buildings
- trees (>50 cm)
- vegetation (irrigated grass/low shrubs)
- Normalised Difference Vegetation Index (NDVI)
- vegetation (other)
- bare ground
- built (impervious tarmac, concrete).

One of the critical parameters being tracked are changes in the tree canopy. Trees are important for providing shading and also cooling via evapotranspiration. Figure 15 demonstrates how changes in land surface temperature are related to tree canopy density.

Further visualisation comparisons of tree cover and land surface temperature in Darwin CBD 2016–2021 can be explored with an interactive tool on the Darwin Living Lab website.

Urban Monitor can extract average solar reflectance for different buildings across the city. Typically, lighter colours (e.g. white) are more reflective and generally absorb and store less heat. Lighter coloured 'Cool roofs' are effective at directly reflecting solar radiation back to the sky, which results in cooler daytime and night-time temperatures, and lower household energy bills. Cool roofs can decrease peak ambient temperature in parts of our cities by up to 1.4°C. Figure 16 demonstrates that there is an increasing number of white (or lighter colour) roofs being used within areas of newer development such as Muirhead and Larrakeyah. It also shows there are opportunities for improvement for any urban renewal projects. Coating products that aim to assist heat reflectance are available (e.g. Super Therm® and Acratex®) and new innovations are in development.[42] Around one third of dwellings in Darwin have solar panels, which appear as non-reflective patches on roofs.

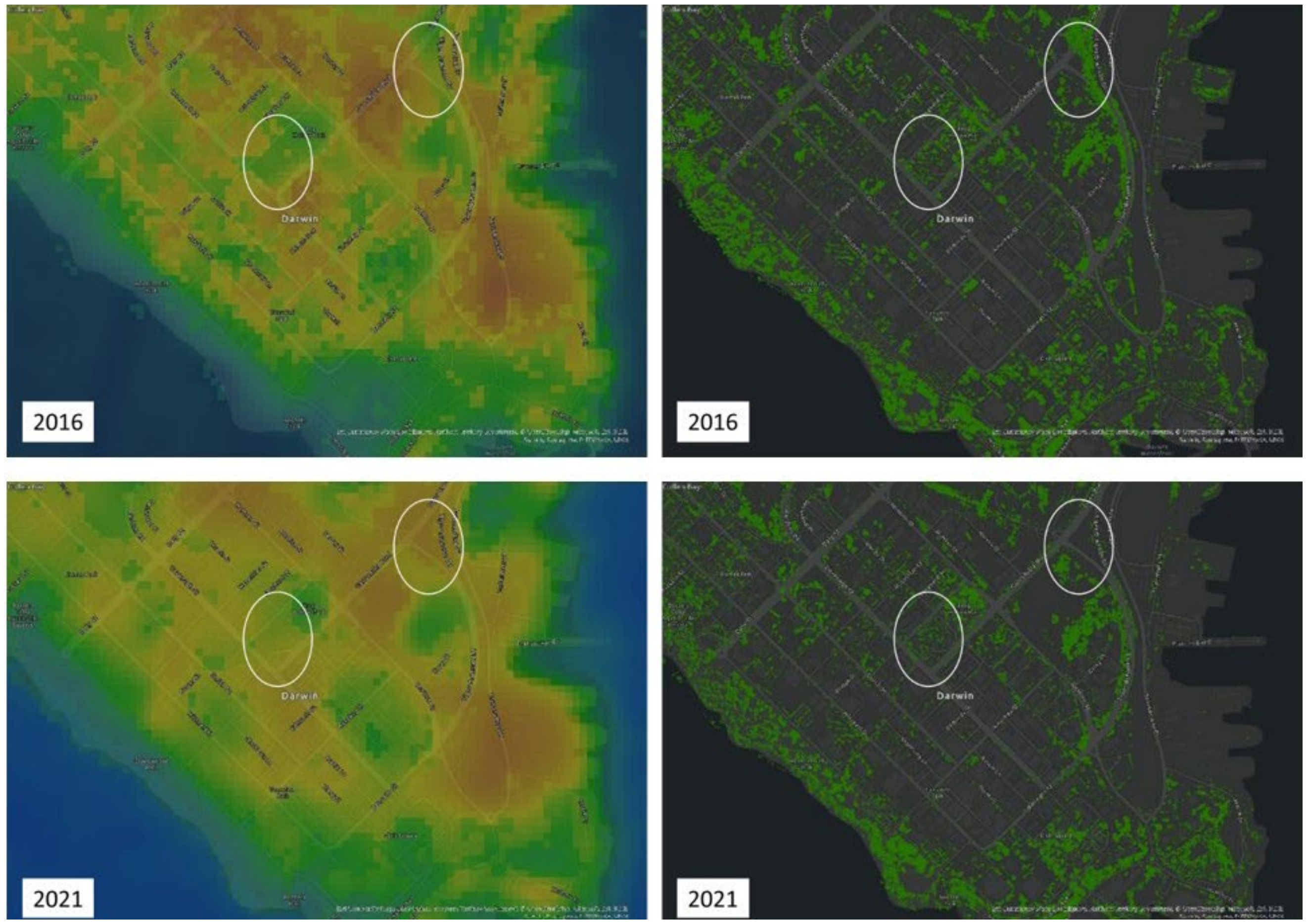


Figure 15. Left: Satellite (Landsat 8) derived land surface temperature maps (30 m resolution). Right: CSIRO Urban Monitor™ tree cover data (20 cm resolution, trees >0.5 m). Areas highlighted demonstrate how losses in tree canopy between 2016 and 2021 correlate with increase land surface temperatures in these areas of Darwin.

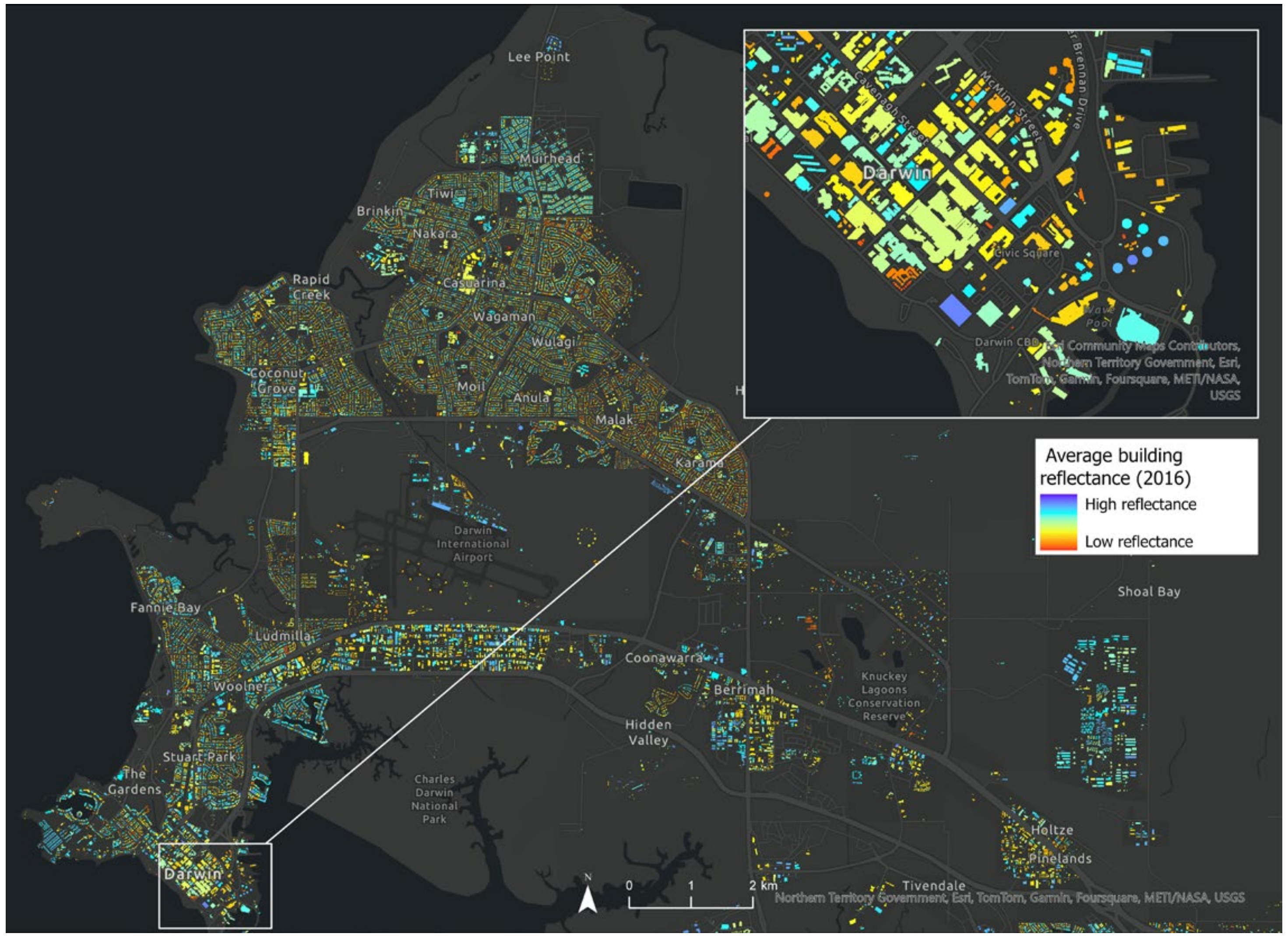


Figure 16. Roof reflectance from buildings within the Darwin LGA in 2016. Blue colours (high reflectance) are associated with cooler roofs, and orange/red (low reflectance) are associated with hotter roofs. The insert shows roof reflectance data for the Darwin city centre.

42 Feng et al. (2022) On the cooling energy conservation potential of super cool roofs. https://doi.org/10.1016/j.enbuild.2022.112076

How best to use reflective surfaces at the street level is a little more complex than roofs. A recent study of heat reflective coatings over 58 km of streets in Phoenix, Arizona (a low humidity climate), evaluated the effects of reflective coatings on air temperature 2 m above street level, surface temperature and mean radiant temperature. Mean radiant temperature (Figure 17) is the sum of all radiation both direct from the sun and reflected from surfaces.[43] The Phoenix study showed reflective pavement to offer minimal difference in air temperature (0.2°C) and decreased surface temperatures up to 8.4°C during the day, yet demonstrated that mean radiant temperature was up to 5.1°C hotter above reflective pavements (at noon) when compared to asphalt concrete road surfaces as a result of the increased reflected energy (think of how people get sunburnt in the snow). While reflective materials assist the overall urban heat island to cool the city, they are not always beneficial at street level, and further work is required to understand how and where to use them in Darwin's humid climate.

The Darwin Living Lab is undertaking surface temperature measurements of the new mural at Royal Darwin Hospital using a thermal camera to analyse variations in heat release across the mural relative to the adjacent panel of the building that is unpainted (Figure 18). Measurements show surface temperature of lighter parts of the mural are around 5°C cooler than darker parts. The analysis can help inform future public art and surface treatments across Darwin by quantifying the influence of different colours in reflecting heat and reducing surface temperatures.

The reduction in heat absorption reduces energy demand (and associated emissions) for cooling the building, as less heat is conducted into the building. The measurements of the mural are part of a broader monitoring program being undertaken around the Royal Darwin Hospital campus, which includes evaluating the influence of the campus greening project in improving outdoor thermal comfort and reducing heat stress risks.

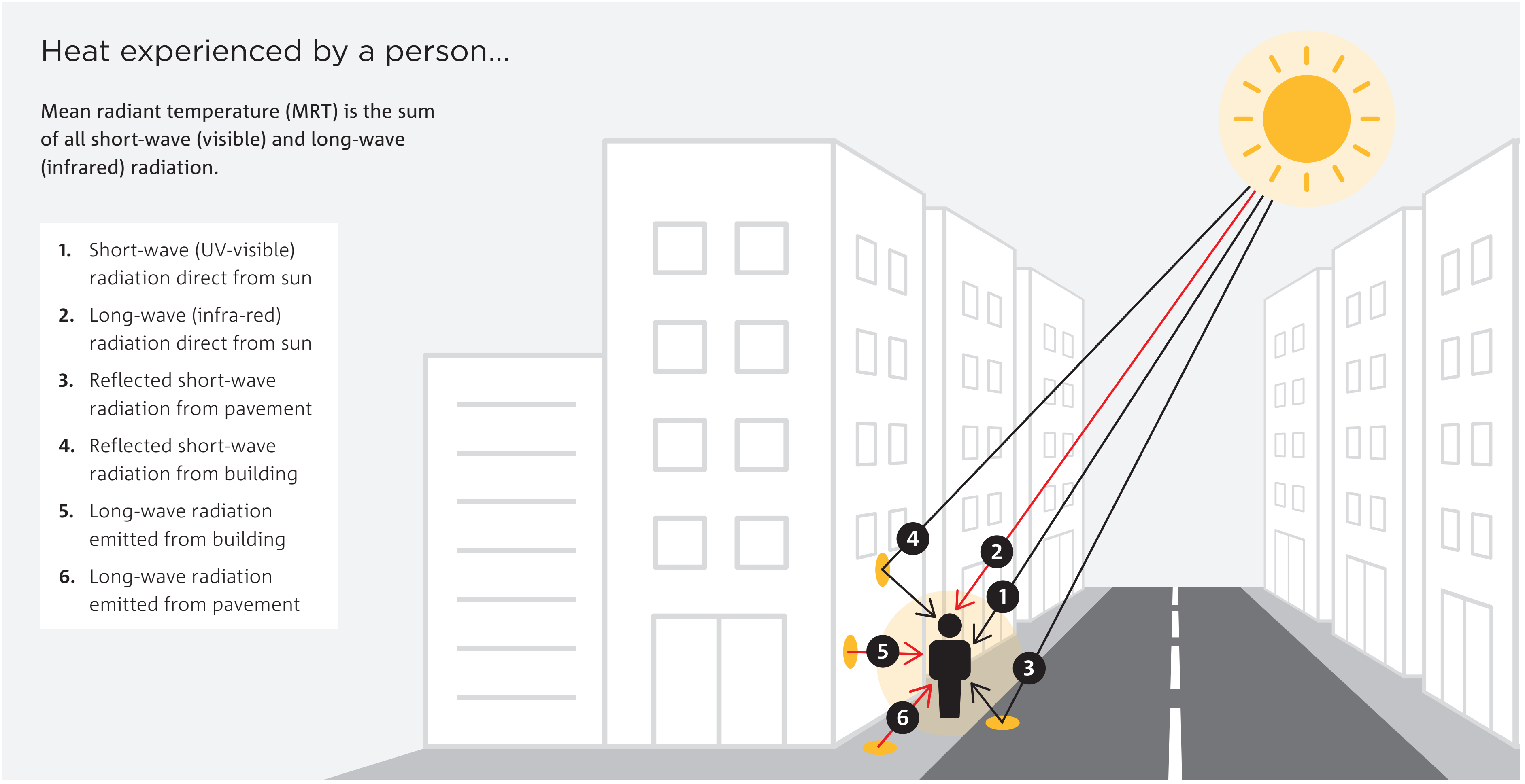


Figure 17. Schematic of components of mean radiant temperature, used to calculate the heat experienced by a person.

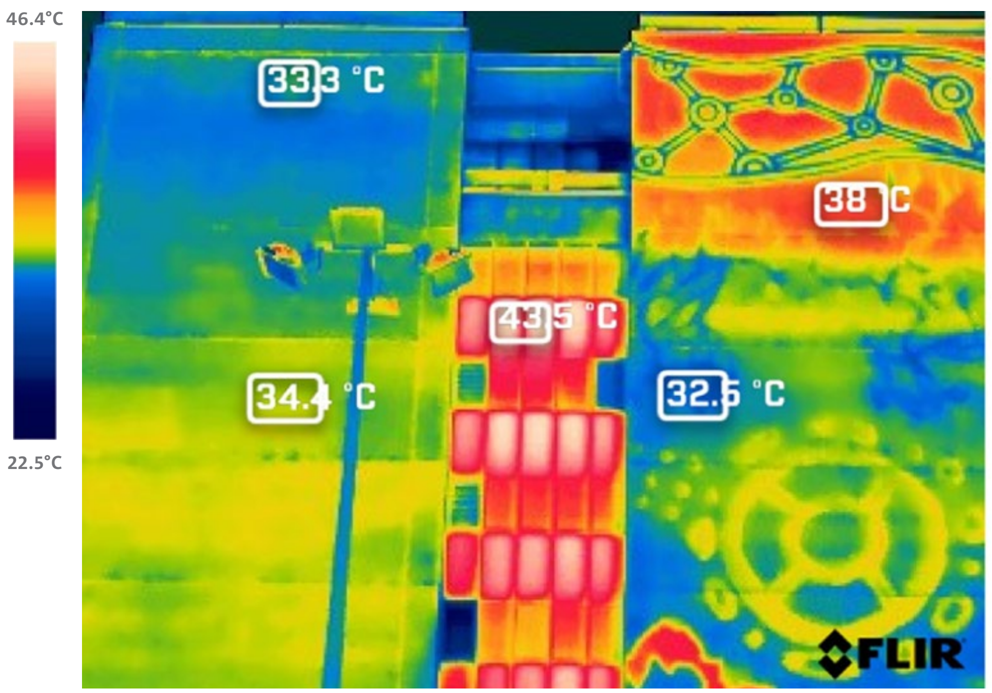


Figure 18. Left: Thermal image of Royal Darwin Hospital showing surface temperature of different coloured building materials. Right: Colour photo of Royal Darwin Hospital building depicting mural.

Green roofs and green walls, although not widely taken up in Darwin, have been used in other cities to reduce urban temperatures by insulating buildings from solar radiation and thus minimising heat emitted from the building. A robust implementation of a green wall in Darwin is shown in Figure 19.

Figure 19. East-facing 'green wall' at St Mary's Catholic Primary School on Cavenagh Street. This simple implementation provides shading for the first floor of the building and lowers the emission of heat to passers-by.

43 Matzarakis et al. (2009) Modelling radiation fluxes in simple and complex environments. https://doi.org/10.1007/s00484-009-0261-0

Any breeze is cool breeze

According to Universal Thermal Climate Index models[44] wind has the result of increasing thermal comfort under almost all conditions experienced in Darwin (i.e. <40°C and relative humidity >30%). Wind speed is typically reduced within the built environment due to the resistance of obstacles, which has previously been observed when comparing windspeeds at Darwin airport and CBD.

Dominant wind directions can be understood through data captured at Darwin airport since 1942. The Bureau of Meteorology reports wind direction and speed at 9 am and 3 pm each day. Compared to the hottest parts of the day (midday – 2 pm), morning conditions have lower air temperatures but humidity is normally higher which, in the absence of other factors such as wind and solar radiation, can lead to similar levels of discomfort.

Observations (Figure 20) show that 9 am winds during the dry season (May–Sep) come predominantly from the south-east and easterly direction. During the build-up months of Oct–Dec, there are no dominant directional movements of wind, and windspeeds are lower on average and rarely achieve classification as a moderate breeze (5.5 – 7.8 metres per second on the Beaufort wind force scale). The onset of the wet season (Jan – Apr) results in morning winds coming predominantly from the west and with higher windspeed.

In comparison, observations at 3 pm show a different story to 9 am. Winds later in the day have a much stronger tendency to come from the north-west during the build-up and wet seasons. Afternoon winds also show a higher average windspeed. This means that even though there is a lack of prevailing wind direction in the morning during build-up months, afternoon winds have a prevailing north-west direction. It is only in the dry season months (May – Sep) that morning easterly and south-easterly prevailing winds tend to continue during the day.

Recently developed Darwin suburbs such as Lyon and Muirhead have placed increased emphasis on street and house orientation and setbacks to allow the prevailing north-west and south-east winds to flow more easily between homes. The Muirhead subdivision has parallel roads orientated 30° to the west of north, orientating along the long axis of lots north-west to south-east and providing 4 m wide building setback distances. These design principles, along with increased Nationwide House Energy Rating Scheme (NatHERS) energy-efficiency ratings of 6–7 and large opposing windows to allow natural ventilation, have been demonstrated to lead to improved thermal comfort outcomes.[45]

From a future perspective, global warming has the capacity to modify larger air patterns, which could lead to a change in the strength and location of winds. The extent of potential changes is unknown at this point in time.[46]

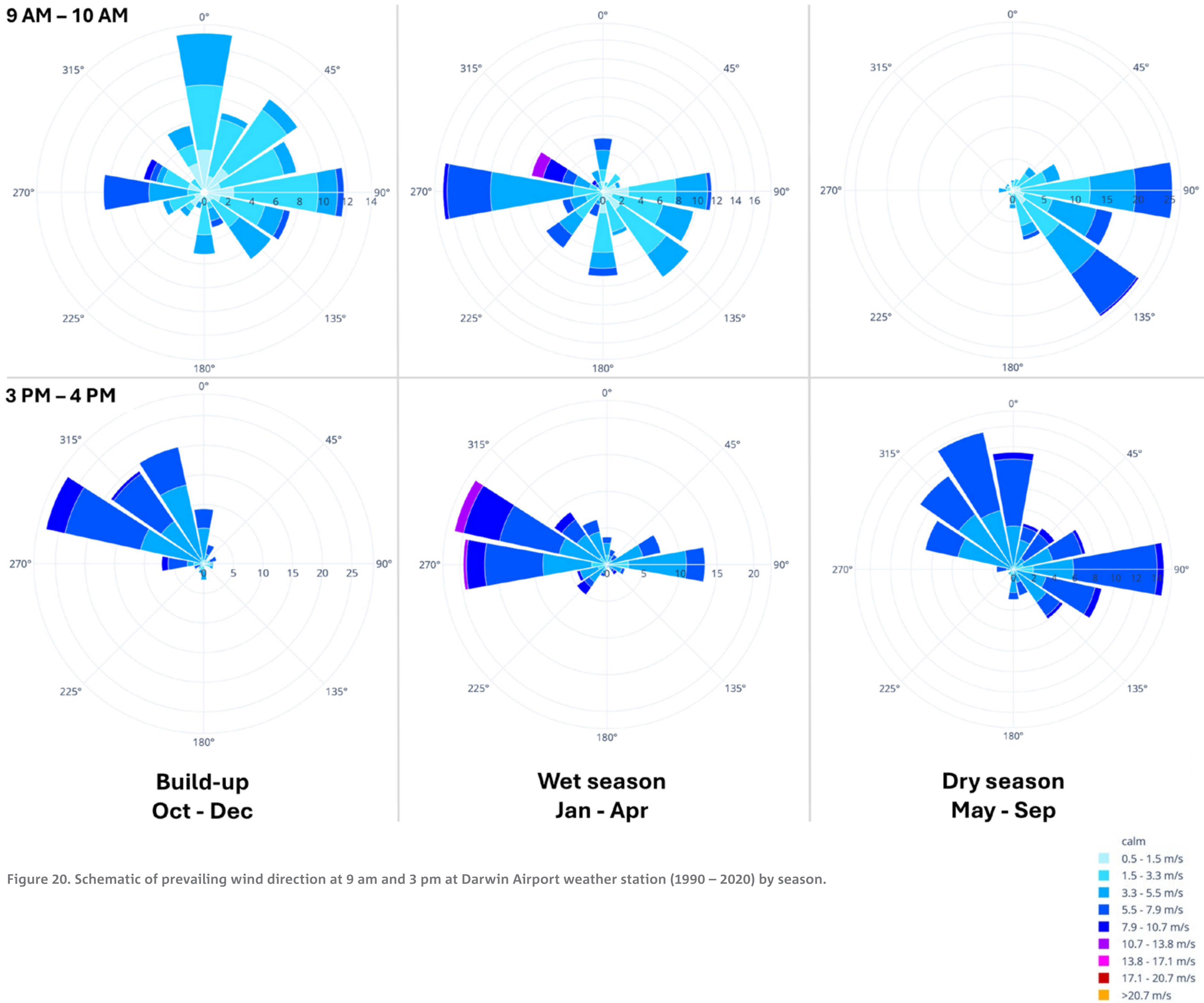


Figure 20. Schematic of prevailing wind direction at 9 am and 3 pm at Darwin Airport weather station (1990 – 2020) by season.

44 Brode and Kampmann (2023) Temperature-humidity-dependent wind effects on physiological heat strain of moderately exercising individuals reproduced by the universal thermal climate index (UTCI). https://doi.org/10.3390/biology12060802

45 Safarova et al. (2022) Thermal comfort in tropical savanna climate the case of home occupants in Darwin, Australia. https://doi.org/10.1016/j.enbuild.2022.112074

46 Personal communication. Brown, NESP Earth Systems and Climate Change Hub, Our Changing Climate.

Best practice for cooling

It is clear that both shade and airflow are critical for staying cool in Darwin. Research worldwide has shown that the most effective cooling technologies for outdoors involve the use of water and associated evaporative cooling, but how these technologies perform in Darwin's humid environment are not well understood. Water is more effective at mitigating heat when the ambient temperature is higher and humidity lower. Darwin Living Lab research has confirmed that land surface temperatures are lower in places that are in the proximity of water bodies. Also the use of water misting fans is becoming more prevalent in Darwin's outdoor restaurants and bars. In Greece, Lebanon and Spain, water sprinklers have been shown to reduce mean air temperatures by 3–4°C and up to 10°C on a 40°C day. The effectiveness of sprinkler and misting systems improves with the generation of smaller water droplets, which increase the water–air surface contact area.[47] Further discussion on the role of water for cooling Darwin can be found below in 03 Water is a Key Resource for Cooling.

An opportunity for Darwin to lead heat mitigation innovation

The Köppen–Geiger climate classification system is used to classify global climates into five main groups, then subgroups. Darwin is classified as being tropical wet-dry (Figure 21), a classification it shares with other global regions with a high population, including Bangkok (Thailand), Ho Chi Minh City (Vietnam), Mumbai (India), and Rio de Janeiro (Brazil).

Future climate projections suggest that other centres across northern Australia (e.g. Cairns and Townsville) will move towards a wet-dry tropical climate. This creates the opportunity for Darwin to export knowledge and technologies for wet-dry tropical living both nationally and internationally.

The Darwin Living Lab therefore ask the community of Darwin to get involved in trialling new heat mitigation innovations. Your view on innovative ways to cool Darwin can be shared via email to darwinlivinglab@csiro.au.

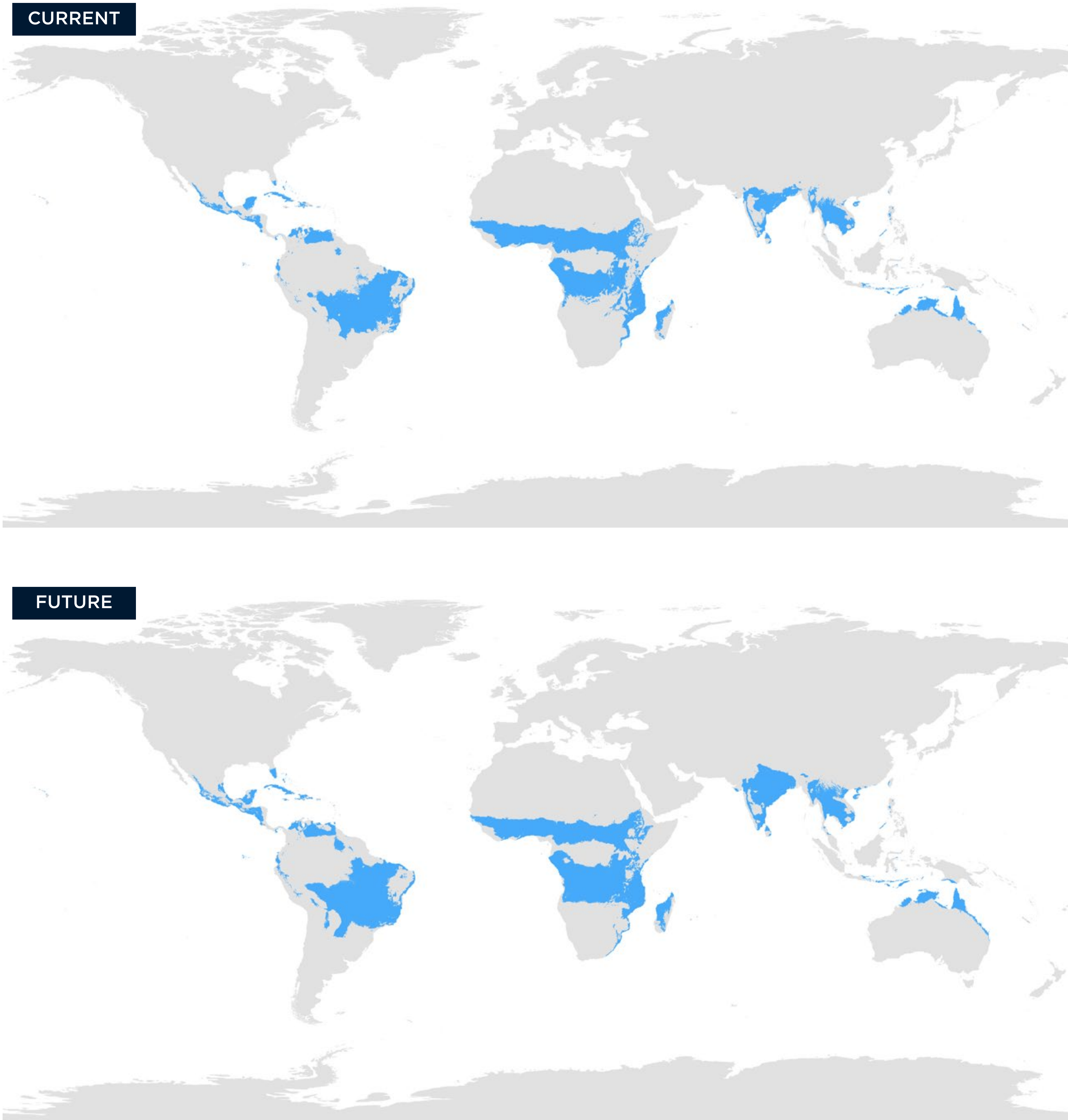


Figure 21. Maps showing regions with current and future tropical wet-dry Köppen–Geiger climate classifications.

47 Santamouris et al. (2017) Passive and active cooling for the outdoor built environment https://doi.org/10.1016/j.solener.2016.12.006

02 Healthy Outdoor Environments

A healthy outdoor environment can be described as a landscape that promotes physical and mental health, and social wellbeing.[48] It should also support biodiversity values – protecting the plants and animals and ecosystems that exist in the area.

In Darwin's hot weather, it is crucial to ensure that the planning of outdoor spaces considers thermal comfort (i.e. not too hot and not too humid) and liveability outcomes for its people. Aligned with Darwin City Deal initiatives, the City of Darwin is striving to be a cool, clean and green city, and its first ever greening strategy was launched in 2021. Actions include revitalising parks and planting trees, landscaping and installing irrigation, and tidying up verges and footpaths, all with the aim of encouraging people to use parks, ovals, walkways and cycling paths.

To measure the success of these programs, it is important to understanding how Darwinites interact with these outdoor environments and how investments return benefits. For example, we know that green spaces offer recreational, social and psychological benefits to people, but they also have environmental and biodiversity benefits, such as providing ecological niches and corridors for multiple species and their ecosystem service benefits – that is, the benefits that humans derive from healthy ecosystems – including pollination, pest control and climate resilience.[49]

Gathering this information helps to inform better decision-making in contested urban planning environment on where and how to deliver green spaces. In tracking healthy outdoor environments there are three main types of indicators (or datasets) that the Darwin Living Lab has begun to collect (Figure 22): outdoor behaviour indicators (i.e. how and how often people use outdoor spaces), human health and demographic indicators, and environmental indicators (e.g. tree canopy cover).

As alluded to in the Overview of Darwin above, achieving healthy outdoor environments is not a straightforward challenge. Darwin's climate has the highest average temperature and humidity in all of Australia. Yet this already hot place is predicted to get hotter. It also has the poorest air quality of all Australian capital cities due to savanna burn reductions during the dry season.[50] Almost all (95%) of Darwin's particulate pollution is attributable to landscape fire, and air quality has become increasingly bad. Analysis of 15 years of airborne particulate matter (PM) monitoring data for Darwin has shown an increasing trend in the annual average concentrations of PM2.5 (diameter <2.5 micron) and more frequent exceedances of national environment protection measures, where PM2.5 exceeds 25 µg/m^3 averaged over a 24-hour period.[51] During the two dry seasons of monitoring, the City of Darwin environmental sensor network showed average daily PM2.5 maximums of 12.3 ± 6.1 µg/m^3. During this time, Environment Protection Authority sites at Winnellie and Stokes Hill measured 24 exceedances of the national environment protection measures for PM2.5. Extreme heat and poor air quality reduces liveability and has significant negative health impacts, particularly for those who spend time outdoors for work and are most vulnerable. Hospital admissions for respiratory and cardiovascular illnesses and asthma-related emergency visits increase on smoky days.[44]

Population increases are another pressure on healthy outdoor environments. Increased population along with economic development will see more demand for built infrastructure, housing and business precincts. Human activities inevitably put pressure on natural systems. Pressures include land use change, resource consumption and harmful substance release. Increased population will create increased demand for quality outdoor green space and its use. However, the allocation and retention of both private and public green space areas competes against increased compact development, competition for land use and the challenge that green spaces are more expensive to maintain relatively to other types of land uses. People also use green spaces in different ways, so it is important to understand community values and expectations.

Urban trees are an important part of healthy outdoors. They are effective in mitigating urban heat (through evapotranspiration) and are critical in Darwin for providing thermal comfort by shading people. However, it can be challenging to grow and ensure the survival of trees in an urban setting, as they are often planted away from other trees and thus exposed to increased heat and higher winds, or in the shade of built infrastructure where they are deprived of direct sunlight. Also, trees in Darwin need to withstand the risk of frequent cyclones and the extremes of water availability through the plentiful wet season and extended dry season. Different tree species will have different abilities to cope with future changes in climate.

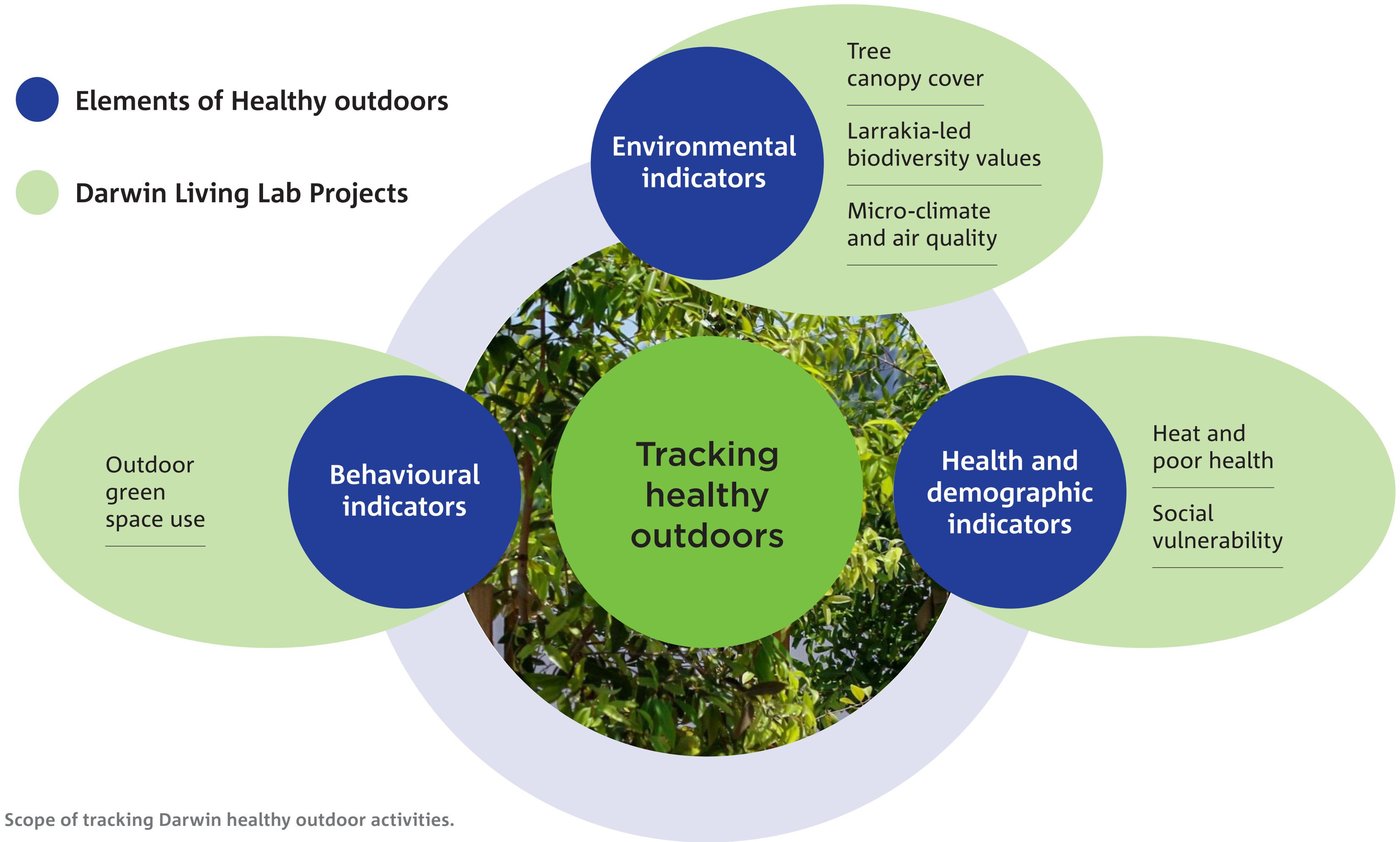


Figure 22. Scope of tracking Darwin healthy outdoor activities.

48 Abraham et al., 2010
49 Lin et al., 2015
50 Tham et al. (2022) https://safeair.org.au/patterns-of-air-quality-around-australia/
51 Jones et al. (2022) Smoke pollution must be part of the savanna fire management equation: a case study from Darwin, Australia. https://doi.org/10.1007/s13280-022-01745-9

Tree canopy cover in 2011, 2016 and 2021

Tree canopy cover in Darwin was estimated at 2,718 ha in 2021, a 30% reduction from 3,869 ha in 2011 according to Urban Monitor™ data. While tree canopy cover increased slightly in 2016 compared to 2011, it decreased from 36% to 24% from 2016 to 2021 in the Darwin LGA. This decrease was primarily owing to Cyclone Marcus in 2018, when **Darwin lost over 1,300 ha of tree canopy cover, accounting for close to a third of its cover in a very short period.**

Several suburbs had very high tree canopy cover (>50%) in 2011, including Alawa, Anula, East Point, Jingili, Ludmilla, Rapid Creek, The Gardens, Tiwi, and Wulagi (Figure 23). Suburbs with relatively low tree canopy cover (<20%) in 2011, such as Berrimah, Casuarina, Darwin City, Holmes, Lee Point, Marrara and Winnellie, kept increasing their tree cover through to 2016; Lee Point and Marrara reached 50% tree cover in 2016. Between 2011 and 2016, suburbs undergoing redevelopment, such as Muirhead and The Narrows, had a decline in tree canopy (Figure 24). Particularly where development does not preserve existing trees, it can take considerable time for these areas to re-establish or increase shade and, in the meantime, they experience higher temperatures. Between 2016 and 2021, in the aftermath of Cyclone Marcus, all suburbs in Darwin decreased their tree canopy cover. Those that experienced the most drastic percentage decreases were Berrimah, Casuarina, Coonawarra, Holmes, and Leanyer.

Aside from the significant impact of Cyclone Marcus, most tree failures can be attributed to a lack of maintenance, such as pruning, or root disturbance caused by cutting or other damage. In addition, the aging tree population of the current urban forest means that many trees will be nearing their life expectancy and will die or have to be removed for safety.

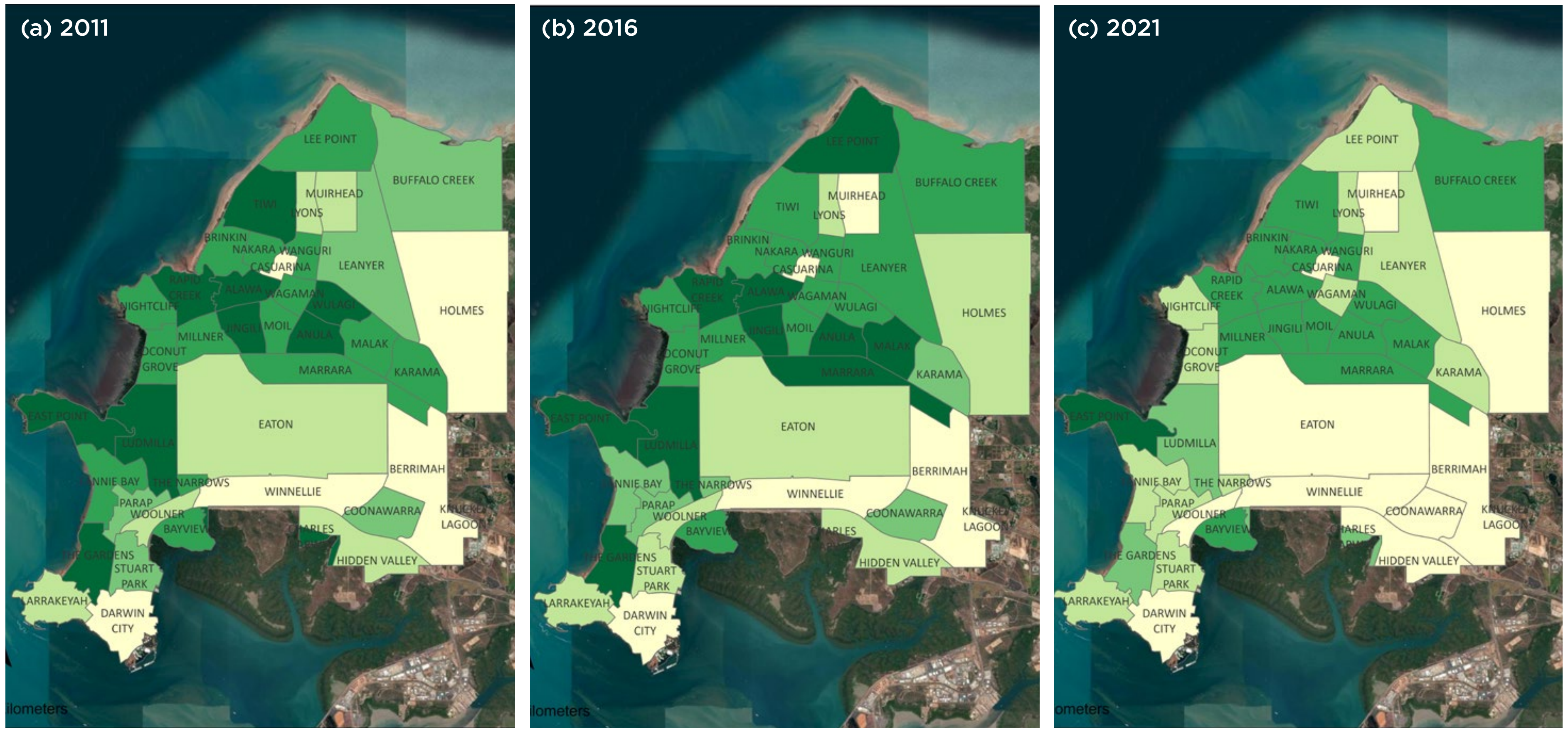


Figure 23. Percentage of tree canopy cover in the Darwin LGA, by suburb, in (a) 2011, (b) 2016 and (c) 2021.

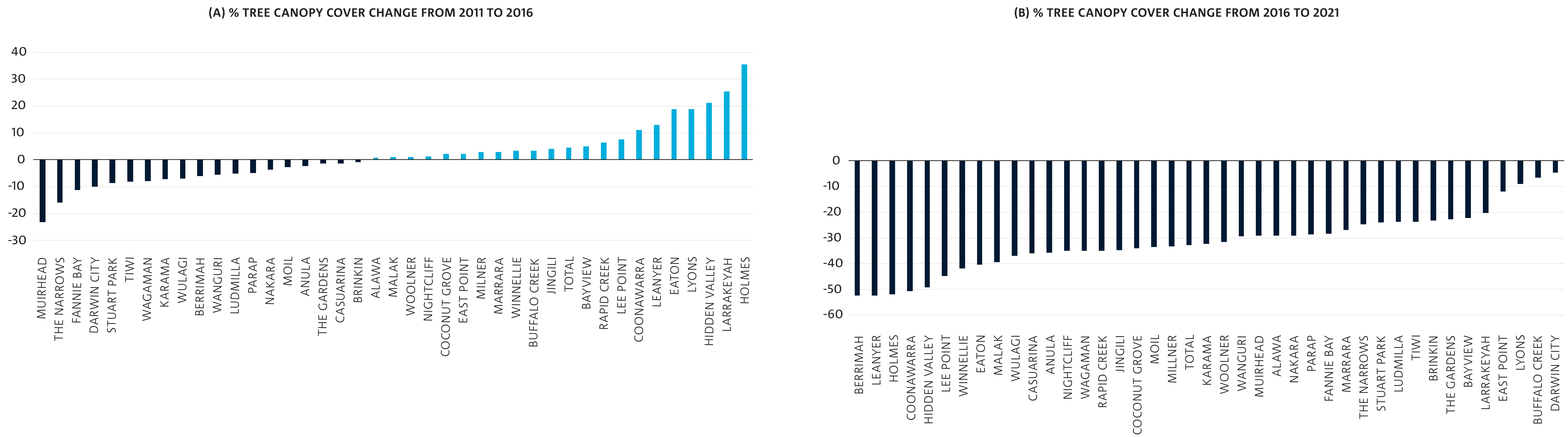


Figure 24. Percentage of change in tree canopy cover in the Darwin LGA, by suburb, in (a) 2011–2016 and (b) 2016–2021.

The use of Darwin's outdoor green space

A CSIRO survey of green space use in Darwin revealed that residents use green spaces very frequently. The largest percentage (24%) of respondents indicated that they visit green spaces 6–7 days a week, and about 72% of respondents said they visit green spaces at least once a week (Figure 25).

On average, Darwin residents spent around one hour at the park per visit, although there were some long visits to other parks, such as Kakadu National Park and Litchfield National Park, with potential overnight stays (Figure 26).

The most frequently visited parks were Nightcliff foreshore, Casuarina coastal reserve and Bicentennial park/esplanade. Access to public green space is not equitable across the city. About 47% of survey respondents had very little access to public open space (<5%) within a 400 m walking catchment, whereas other respondents could access up to almost 30% of public open space within 400 m (Figure 27).

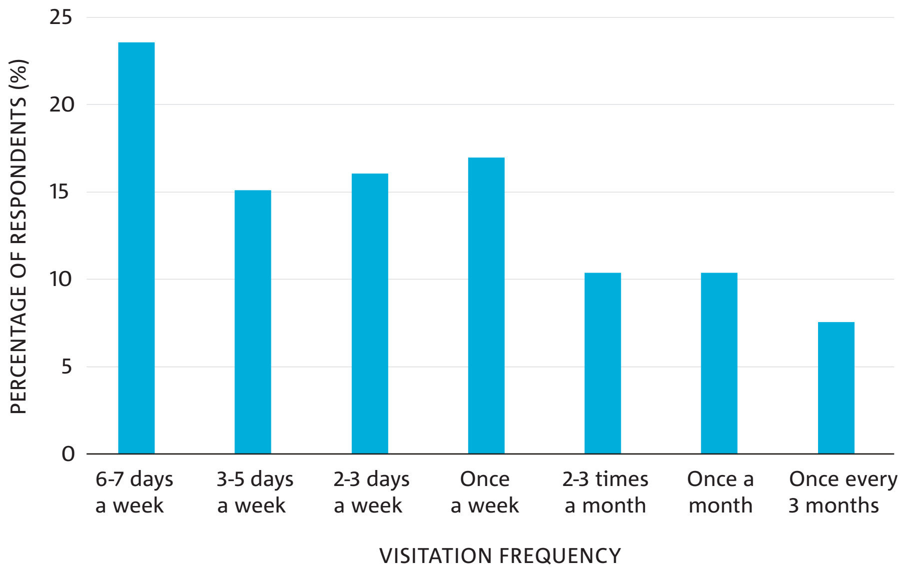


Figure 25. Percentage breakdown of visitation frequency of Darwin residents to green spaces.

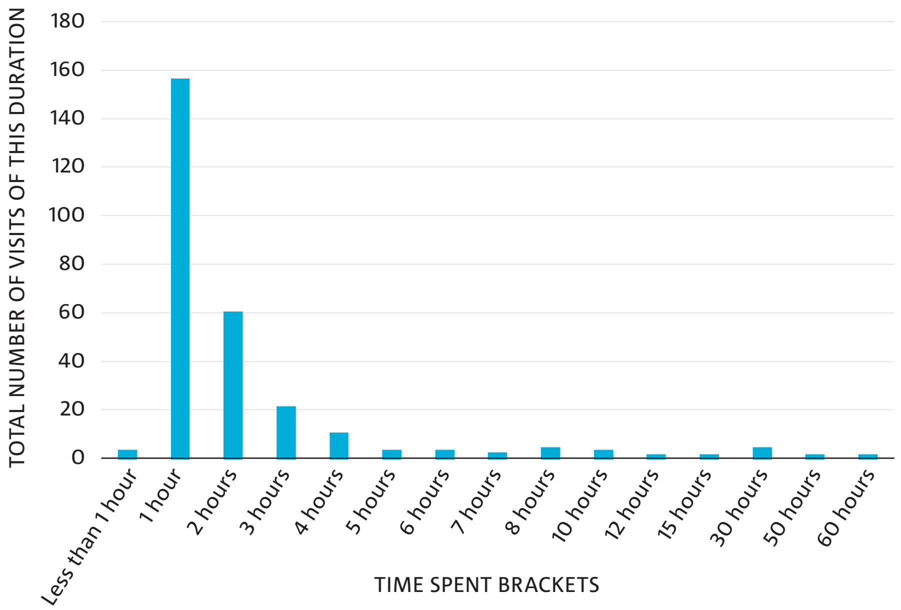


Figure 26. Time spent per visit by Darwin residents to green spaces.

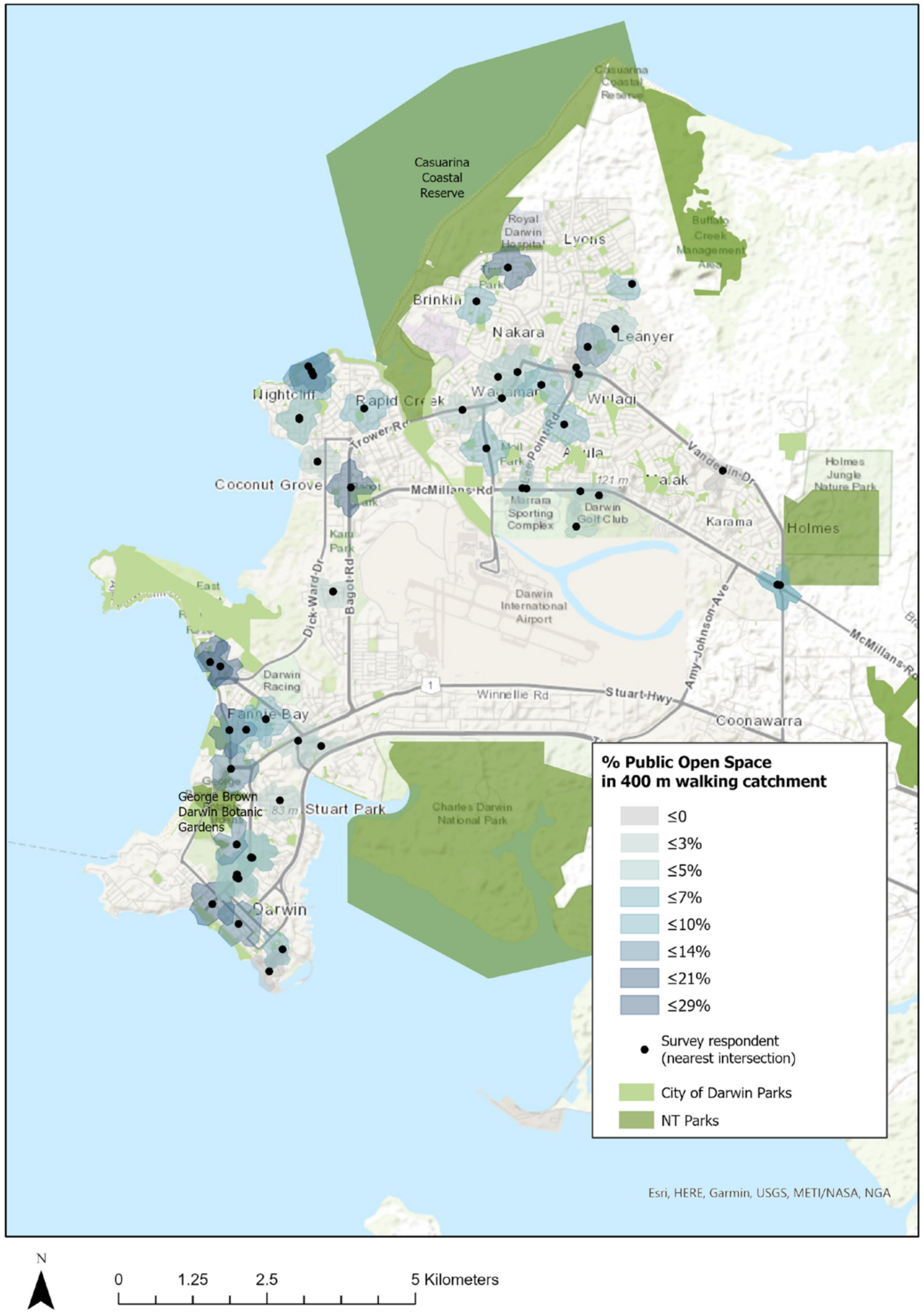


Figure 27. Access for Darwin residents to green open spaces within a 400 m walking catchment.

Table 1 and Table 2 explore what attracts people to the parks of Darwin, and what stops people from going to parks.

Table 1. What attracts people to visit Darwin's green spaces (in order of frequency of response).

COMMENT CATEGORY	FREQUENCY	EXAMPLES OF COMMENTS
Atmosphere	51	Atmosphere, views, vibes, beauty, fresh air, shade, cool, outdoors
Nature	43	Plants, trees, greenery, vegetation, native vegetation, animals, birds, unspoilt, natural
Water	36	Creeks, rivers, beaches, ponds, lakes, waterfalls
Facilities – other	22	Other facilities, variety of facilities, BBQs, amenities, café, coffee trucks, markets
Accessibility	19	Close to home or work, good parking, transport options
Peace and quiet	19	Peace, quiet, uncrowded, relaxing, safe
Facilities – sports/ exercise	18	Specific facilities for exercise or sport (running tracks, cycling tracks, cricket, golf, basketball, etc.)
Facilities – walking	14	Walking, walking tracks, a good place to walk
Space	12	Big, open space, large space
Cleanliness	9	Clean, well maintained, curated, well designed
Facilities – dogs	9	Facilities for dogs, off-leash areas, dog-friendly
Community	8	Neighbours, other people, family, friends, community, people watching
Facilities – kids	6	Facilities for kids, playgrounds, kid-friendly

Green spaces are an important part of the 'atmosphere' of Darwin.

Table 2. Barriers for visits to green space (in order of frequency of response).

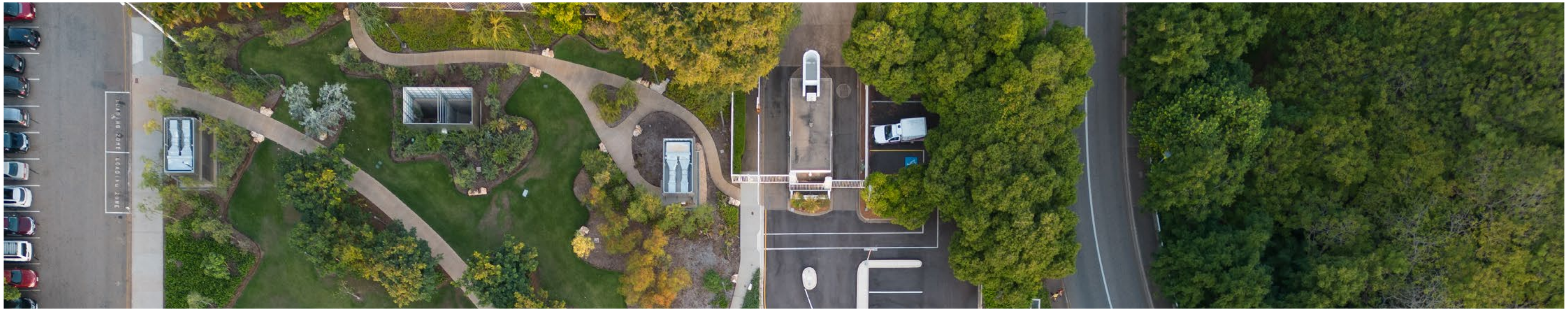
COMMENT CATEGORY	FREQUENCY	EXAMPLES OF COMMENTS
Poor weather	37	Bad weather, heat, mud, rain, sun, UV
Too busy	22	No time, busy with work/home/other things
Safety issues	22	Homeless people, drunk people, careless cyclists, antisocial people, itinerants, too isolated
Animals	17	Loose/aggressive dogs, swooping birds, mosquitoes, bugs, spiders, snakes
Missing features	17	Includes built facilities (amenities, paths, seating, lighting), natural elements (trees, open space, views, water), shade
Crowding	11	Crowds, noise, traffic, smog, noisy kids
Litter/poor maintenance	10	Rubbish, litter, graffiti, dog poo, old facilities, poorly maintained facilities
Access issues	7	None close, no public transport, poor parking, paid parking
COVID-19	3	Due to lockdowns or due to choosing to avoid other people
No interest	2	I don't like parks/nature/outdoors, I have my own yard/ garden
Health issues	1	Poor health, allergies, mobility issues, old age

Larrakia biodiversity values

Biodiversity is an underappreciated component of Darwin's liveability, sustainability and resilience. The natural systems and species of Darwin provide the backdrop to all aspects of life. The Larrakia people, the traditional custodians of the Greater Darwin region, hold knowledge of and insights into Darwin's biodiversity that are critical to effectively maintaining, managing and enhancing these assets. A Larrakia-led Darwin biodiversity project has sought to identify important natural places and green spaces around the city, canvassing residents' and visitors' feedback via an online survey that explored questions around Darwin's biodiversity and its interaction with personal values, heat and liveability.

The online survey received feedback from 189 participants and provided the following key learnings:

- Darwin's character is largely derived from natural places and green spaces.
- The importance of natural environments is a shared value across demographics (i.e. traditional owners and the general population).
- Among a range of factors that reduce liveability, the key factors were humidity, heat/temperature, invasive plants, pest animals and smoke from fires. Factors that affected liveability to a lesser extent were dangerous species and shopping options.
- Important factors for improving liveability include access to natural places, parks and green spaces, outdoor lifestyle, Top End natural places, nature sounds and wildlife in suburbs.
- Favourite places to visit include Casuarina coastal reserve, Lee Point, Freshwater (Rapid Creek), Nightcliff foreshore, East Point and George Brown Darwin Botanic Gardens.
- Easy access to nature is highly valued by the community and contributes to wellbeing; however, these natural systems are stressed by urbanisation.
- Aspects that impact the connection between community and Country include:
  - pests, and weeds causing larger fires
  - climate change
  - tree clearing
  - restricted access to Country
  - loss of natural, safe places to swim and keep cool
  - lack of public transport to Darwin's natural places.



Extreme heat and air-quality impacts

The University of Tasmania led research that explored how Darwinites with vulnerability to outdoor heat and poor air quality manage their symptoms and what coping mechanisms they use. Focus group discussions were conducted with identified vulnerable individuals: outdoor workers, teachers and carers, and sports people. There was a common perception among participants that it was getting hotter, and that heat impacted their work, health and activity, as did seasonal smoke. Adaptative behaviours were adopted by participants to combat hotter temperatures and poor air quality from seasonal smoke. A lack of policies around managing increased temperatures and seasonal smoke and a lack of appropriate infrastructure were perceived as factors that resulted in work practices and sporting activities not adapting to environmental changes and 'doing the same things as usual' (which had health and activity implications).[52] Table 3 presents a selection of responses given in the focus group discussions as part of the research.

Table 3. Adaptive behaviours to combat heat and smoke in Darwin

ADAPTIVE BEHAVIOUR	EXAMPLE COMMENTS
Seeking shade	Sports people – *"have a shade break. Shorter, sharp bursts and then go in the shade."* *Outside workers – "when we stop we don't stand out in the sun and talk about things, it's just shade."*
Seeking air-conditioned buildings	Outdoor workers – *"we will use other people's air conditioning, so we will go into the foyer of a hotel or we will go down an arcade… it's deliberate, we've gone through different laneways…so there's a blast of the aircon."*
Ice applications to decrease body temperature	Sports – *"before I go on the field… I fill my bra up with ice. And then I fill it up every time I sub off."* Outside workers – *"yeah we have water coolers and an ice machine."* Sports – *"each team gets its own heat management kit. So it's the big ice buckets and towels and that all gets distributed at the start of every season, along with a list of what you do." "At higher-level events, we have inflatable baths that we set up as ice baths."*
Drinking lots of water	Outdoor workers – *"drink lots of water while you're working. I've had some days where I've drunk nine litres of water." "If it's like really hot, I'll call up the boss and tell him to give me a purchase order for some electrolytes."* Sports people – *"a couple of sips of water and a sip of Gatorade, always just keep the hydrolytes going. And then myself, if I'm really bad, I will have hydrolytes after."*
Wearing suitable clothing	Outdoor workers – *"if I know it's going to be a really hot day, even though it sounds counterproductive, long sleeve shirts, long sleeve pants because of the sun."*
Avoiding the hottest part of the day	Outdoor workers – *"we've started at two in the morning before, six, seven, just depends. Normally is eight." "We try to avoid the really stinking hot part of the day."*
Avoiding the smoky outdoors by closing windows and doors and using AC	Carers – *"our aircons are filtered. So, they're recycling air through the centre, but they're filtered. We get filters checked as well to make sure that they're giving us as clean aircon as possible."* Outdoor workers – *"when you're working outside, there's not much you can do about it. But back at home, shutting all the doors and windows and turning the aircon on, you're going to have a bit of a decent sleep and escape it."*

Although heat and poor air quality affects all Darwinites to some extent, disadvantaged populations are most at risk and least equipped to cope with these pressures.[53] The Darwin Living Lab has produced an analysis of areas of Darwin where residents are statistically most vulnerable to climate extremes (Figure 28). This includes people more likely to have heat-health risk factors (e.g. those aged under 5 years or aged 65 years and over, those who need assistance, or those who are likely to have health conditions), and people who are likely to have decreased ability to respond to heat extremes (e.g. those from low-income households).[54]

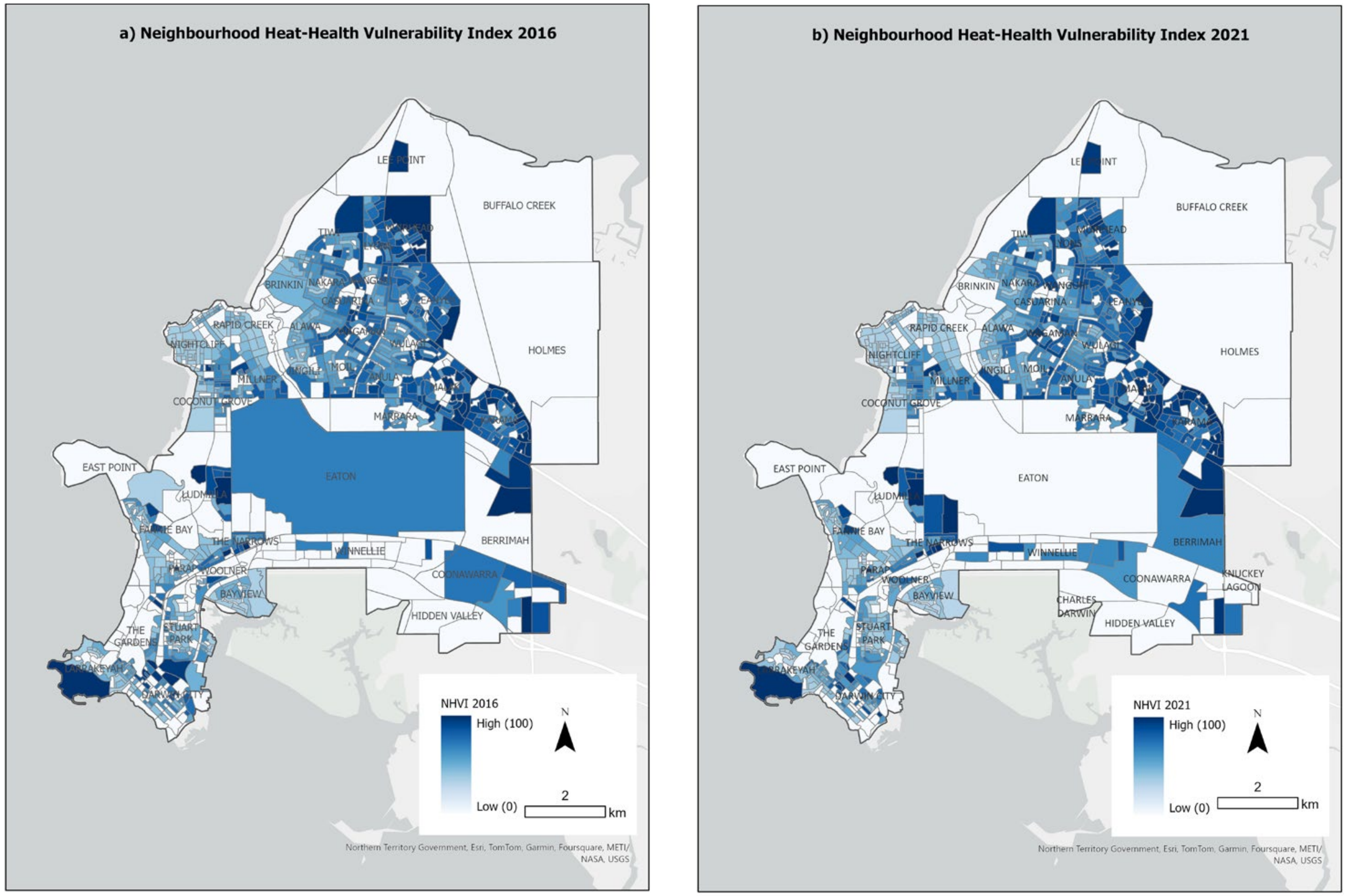


Figure 28. Neighbourhood Heat-Health Vulnerability Index. Derived from the median land surface temperature of the dry seasons of 2018 and 2019, and neighbourhood heat-health risks based on ABS 2016 and 2021 Census data.

52 Campbell et al (2022) Managing extreme heat and smoke. https://doi.org/10.3390/su142113805
53 Reckien et al. (2018) Equity, environmental justice, and urban climate change. https://doi.org/10.1017/9781316563878.013
54 Meyers et al. (2020) Mapping land surface temperature and heat-health vulnerability in Darwin, CSIRO.

Climate challenges

A warming climate in Darwin and its effects on outdoor activities are set to have profound socioeconomic consequences. Darwin's appeal as a tourism hub is an escalating risk due to warming trends, threats to biodiversity and coastal erosion issues. For example, higher temperatures may render outdoor activities less viable or enjoyable. This environmental shift is also likely to drive up costs in several sectors, including health (both private and public), energy and insurance, exerting additional financial strain on low-income populations. Consequently, government expenditure may need to rise to address these challenges through adaptation and mitigation strategies.

How can we make a difference?

During 2011–2021, Darwin's building area footprint increased by about 1.3 km^2 (Figure 7) – a change that impacts the total area of green space. Darwin is still without shade trees 3 years after Cyclone Marcus.[55] This has led to an increase in areas with exacerbated urban heat, an increase in active transport paths without proper shading, and a reduction in aesthetic qualities of the overall urban environment. Planting and maintaining urban trees is a costly exercise; therefore, it is best that future tree planting be targeted towards areas where benefits could be maximised, such as where active transport occurs (e.g. along walking paths or bike paths), and areas of high recreational value (e.g. urban parks and around sporting fields). The City of Darwin strategy to restore tree canopy and a news article on restoring shade for the people provide more information. Other areas of importance include those areas that have high heat-health vulnerability (Figure 28).

Figure 29 shows the tree canopy cover along the City of Darwin's footpaths and shared pathways. It shows that paths in East Point, with largely public open space paths, had 57% tree canopy cover within the 10 m corridor used to estimate shading benefits. Rapid Creek and Ludmilla had 24% tree canopy cover along active transport paths, followed by Tiwi and Jingili (23%). The suburbs with the lowest tree canopy cover along active transport paths were Muirhead and the industrial suburb of Winnellie (4%).

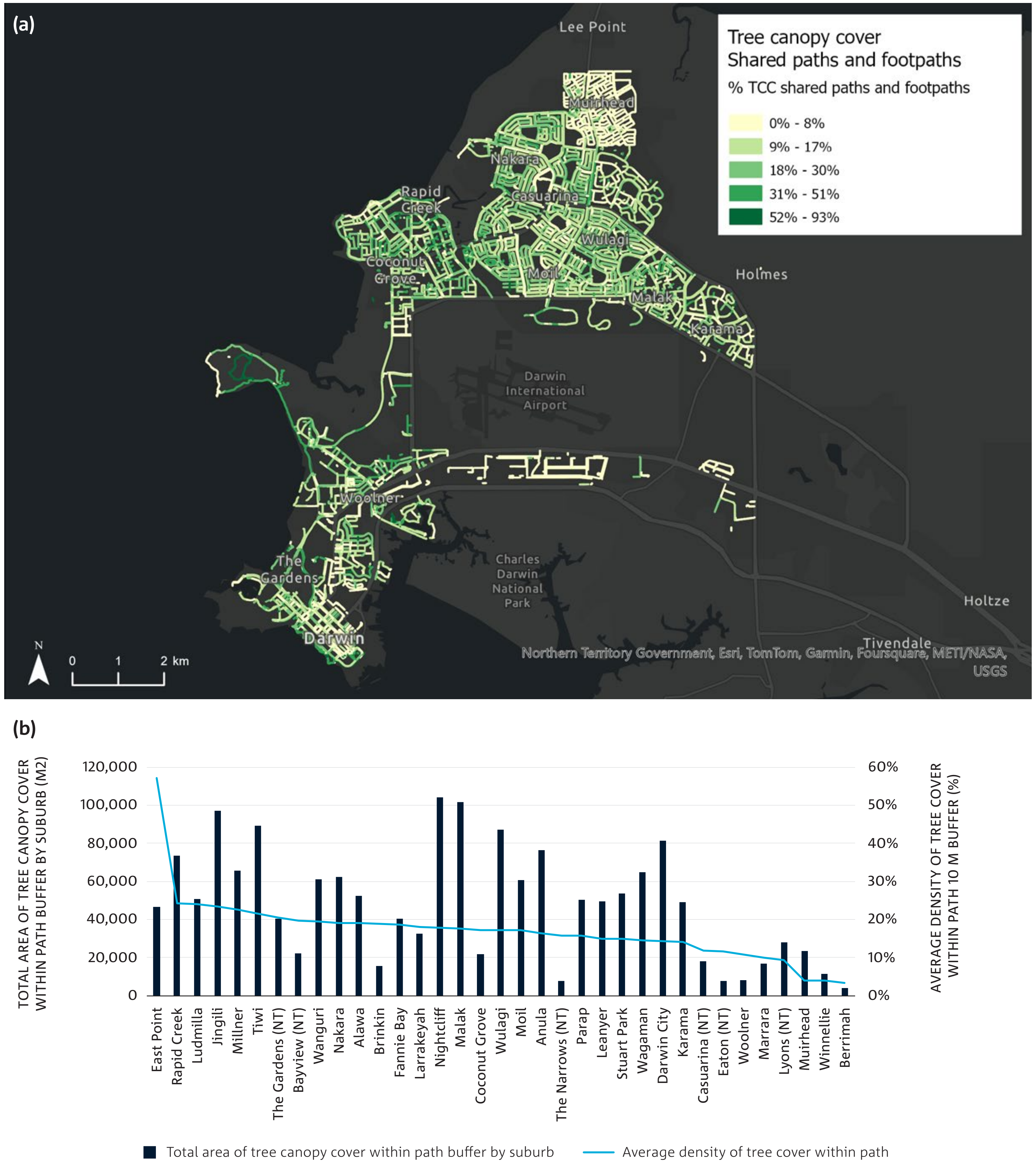


Figure 29. Tree canopy cover over shared paths and footpaths: (a) map of percentage tree canopy cover within 10 m buffer, (b) Sum of area within pathway 10 m buffer. Only trees that have a height exceeding 3 m are included.

55 https://www.abc.net.au/news/2022-12-04/darwin-s-lack-of-shade-trees-amid-heatwaves-in-hot-season/101723626

The City of Darwin has a list of preferred trees with high cyclone resilience, providing good guidance as to which tree species to plant in the future to avoid further canopy loss from cyclones. Other tree species that could be considered for planting in the future include those that are resilient to heat, tolerant to low rainfall, and overall well-suited to Darwin's changing climate. Best practice approaches to urban greening and selection of tree species should provide the highest ecosystem service benefits to the urban environment, which would also need to support biodiversity outcomes. Recent Charles Darwin University research has explored the relative performance of different tree species in Darwin to assist with heat mitigation. Interestingly, palm trees showed the poorest performance, but there is a wide range of species that offer high shading and heat mitigation potential.

The Darwin Living Lab developed a Neighbourhood Heat-Health Vulnerability Index of the periods 2016 and 2021, to identify areas where residents may have higher risks of heat-related illness and lower adaptive capacity (i.e. fewer economic resources to cool their homes).[56] It found that several areas in the suburbs of Berrimah, Darwin City, Karama, Larrakeyah, Malak, and Muirhead, had a high vulnerability index in 2016, with Muirhead ranking particularly high; most of the area in these suburbs is in the highest scale (above 90). Several of these suburbs – for example, Berrimah, Darwin City and Berrimah – have relatively low tree canopy cover (<20%). Using the same heat data of 2018–2019 (land surface temperature), we contrasted the heat-health risks derived from 2016 ABS data with the 2021 dataset. In 2021, Karama and Malak had the most considerable proportions of the suburb areas with a very high Neighbourhood Heat-Health Vulnerability Index.

Residents of Darwin can, and should, take action to contribute to creating a healthier outdoor environment. Actions might include choosing a lighter roof colour, planting trees in the front or back yard, including from City of Darwin plant giveaways, and experimenting with green walls.

Planning reform continues to occur in the NT, with the Designing Better project, incorporating heat mitigation measures into planning[57] and progressing other measures to improve liveability outcomes.

There are many opportunities for property and business owners and developers to achieve collective outcomes, such as planning and investing at property boundaries to shade public space (i.e. install awnings, balconies or plant a shade tree). Integrated planning, which continues to be an important objective for all cities, provides an opportunity for Darwin to undertake a local and more consultative approach to planning. To support this intent, the City of Darwin has been rolling out its approach to community-informed planning via the EngageDarwin portal, and the Darwin Living Lab has been holding 'Chalk the City' events to seek community input on heat mitigation responses that they would like to see.

Perhaps local discussions could explore the question of what time off day the community would like to use outdoor spaces. Being cooler in the evening, sports are shifting towards night events. Is there an appetite to better activate community spaces into the evening? Is this a cultural change that Darwinites are seeking in their suburbs? What would need to happen to deliver lighting and amenities and ensure appropriate safety?

Regarding air quality, are there opportunities to program savanna burns to minimise the health impacts of poor air quality in populated areas of Darwin? Could programming of savanna burns use advanced weather projections and provide educational opportunities for landholders and Indigenous rangers?

Resources

- NT Government heat stress guidance
- NT Health heat stress guidance
- Bureau of Meteorology Heatwave Service for Australia
- AirRater interactive app to assist to manage personal health issues related to air quality
- City of Darwin strategies to progress a cool, clean and green city
- Australian Climate Service, understanding heatwaves and their impact

56 Meyers et al. (2020) Mapping land surface temperature and heat-health vulnerability in Darwin, CSIRO.
57 https://www.abc.net.au/news/2023-04-03/cooling-our-cities-with-heat-mitigation-in-a-warming-world/102169546

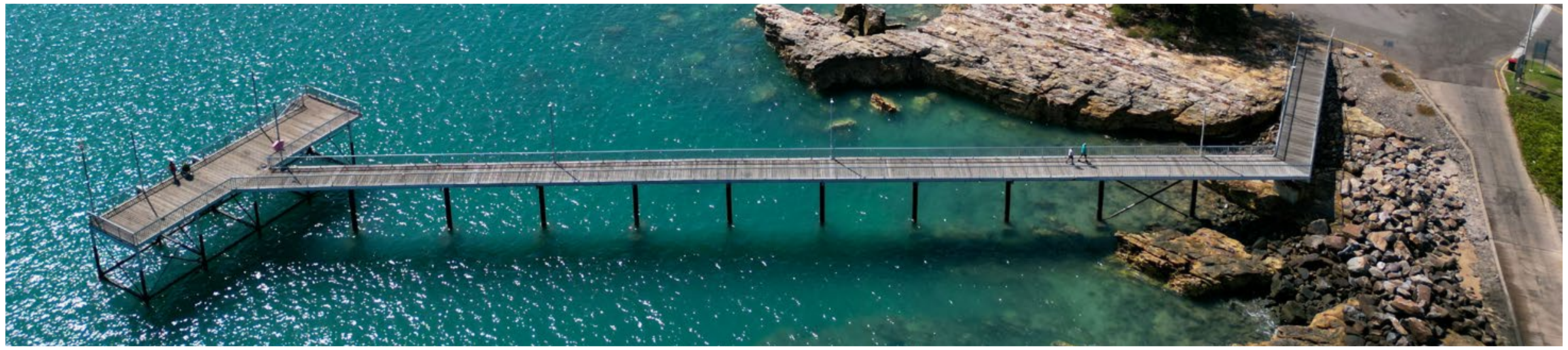
03 Water is a Key Resource (for Cooling)

The Water Situation section in the Overview of Darwin at the start of this e-book touched on some of the challenges with water in Darwin. As a result of Darwin's wet-dry tropical climate and high water usage, urban water demand often exceeds the sustainable yields from surface water catchments. Population growth, economic growth and climate change are likely to exacerbate these challenges.

Water is a fundamental need for a liveable, sustainable and resilient city. It is needed for drinking, cleaning, washing and sanitation, as well as urban greening, biodiversity, urban agriculture and industry. Water also plays an essential role in creating a cooler and more liveable Darwin – not only to irrigate shade trees and vegetation to combat the urban heat island effect, but for innovative strategies such as water misting systems which, as described above, are useful for outdoor cooling and are becoming more prevalent in Darwin's outdoor restaurants and bars. Open water bodies also play a role in cooling, with cooler parts of the city tending to be in the proximity of the coast or near a water body, as well as those areas where water has sustained healthy tree and vegetation growth (Figure 11).

There are several key questions about water that the Darwin Living Lab considers important to learn more about:

- With a warming climate, what role can water play to offset the risks of extreme heat by providing improved cooling and greening benefits to Darwin?
- If water is to play a greater role in cooling Darwin, to what extent will this add further pressure on exceeding sustainable water yields?
- Given that large amounts of water are used for irrigation in Darwin, what are the opportunities for water-use efficiencies?
- Is it possible to keep more water in the Darwin landscape through effective water-sensitive urban design or to develop climate-resilient water supplies such as recycled water?



How Darwin uses water

While Darwin's residential water use has declined over the past decade, it is still twice the average of other Australian capital cities (Figure 30) and it is still high when compared to other centres in northern Australia (Figure 31).

Most (59%) of this water is used for irrigation of gardens, 22% for indoor uses and 7% for pools, and a substantial 12% is attributed to water leaks. Water usage for irrigation is influenced by the wet-dry tropical climate, where there is very little rainfall over the dry season and a need for substantial irrigation to maintain green spaces (Figure 32).

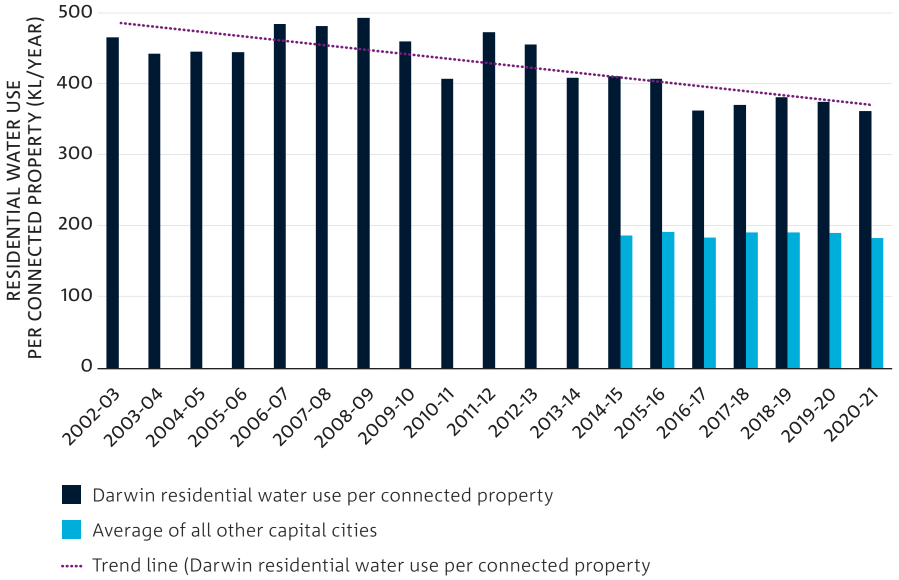


Figure 30: Greater Darwin annual residential water use per connected property (in kilolitres). Source: Bureau of Meterology, Urban National Performance Report.

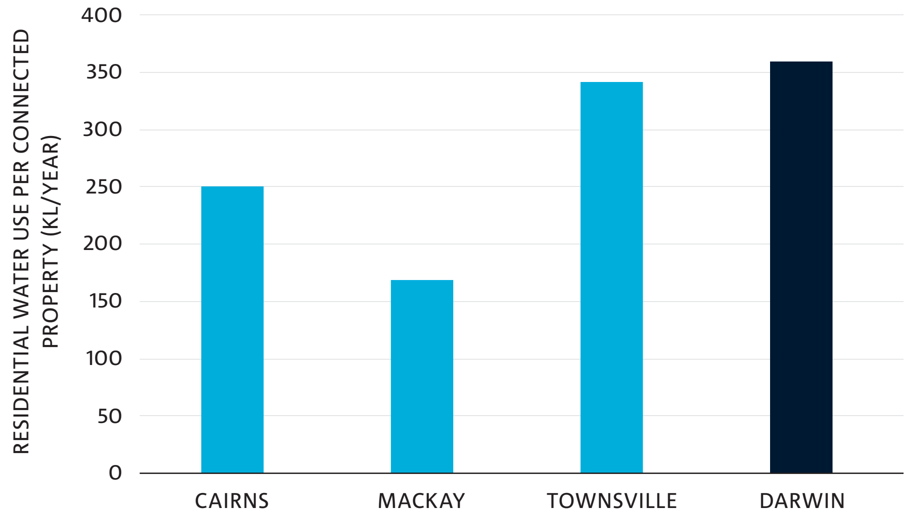


Figure 31: Residential water demand for northern Australian cities (2020–21). Source: Bureau of Meterology, Urban National Performance Report.

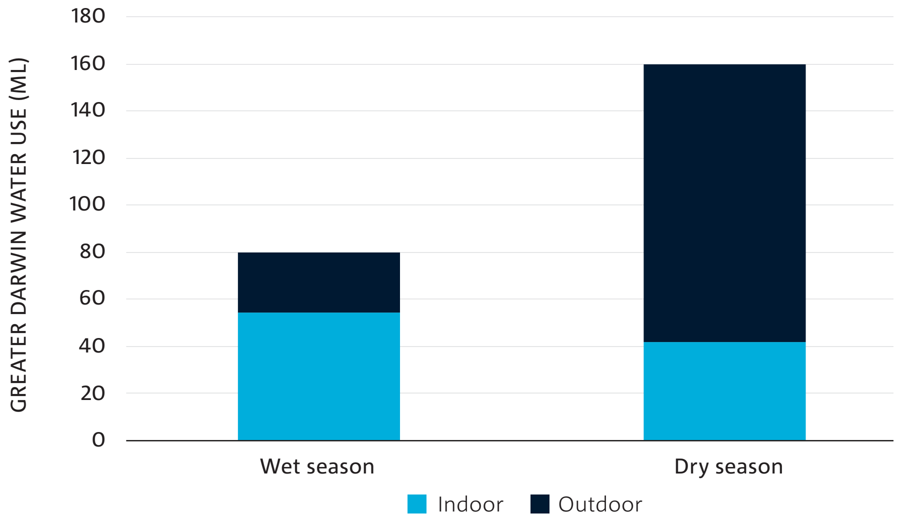


Figure 32: Darwin seasonal water use (in megalitres). Source: Bureau of Meterology, Urban National Performance Report.

Analysis of irrigated ground cover across Darwin

Since irrigating grasses and shrubs is a significant driver of water demand in Darwin (especially during the dry season), the Darwin Living Lab explored Urban Monitor™ land cover and surface models for 2011, 2016 and 2021 to understand how irrigated grass and shrub cover varies across Darwin suburbs. Grasses and shrubs are classified as all green vegetation less than 0.5 m in height, and typically receive watering via human or natural means. At the time of year the photographs were taken, unwatered land cover tends to be dry or brown and Urban Monitor™ classifies these areas as bare ground.

Aerial imagery used for analysis was obtained in the dry season on 4 June 2011 and 29 June 2016, and between 31 July and 16 August 2021. The analysis of irrigated grasses and shrub cover in relation to land use was based on cadastre (i.e. land parcel boundaries) and planning zones (Figure 33).

Figure 34 compares the area of irrigated grass and shrubs per lot within Darwin suburbs. To undertake this analysis, we used 2024 cadastre to determine low-density and low-medium-density residential lots and estimated the building footprint and irrigated grass within each property boundary.

Marrara (established around 1984) had the highest average area of irrigated grass and shrubs (96 m^2) per residential lot, which was three times the average across all Darwin suburbs. This is influenced by a large lot size (average ~1,298 m^2) and perhaps the setting within the golf course estate.

Older suburbs in Darwin tend to have larger lot sizes and newer suburbs smaller lots sizes and potentially less room for green space. Newer northern suburbs (Lyons and Muirhead) have the highest building to lot ratio – 0.48 and 0.44, respectively. Interestingly, along with Marrara, they also had the highest proportion of irrigated grass on the unbuilt area of the lots (~10%).

Older suburbs, such as Nightcliff and Rapid Creek, although on larger than average lots, had relatively low average areas of irrigated ground cover on residential lots, which in part could be explained by high tree canopy cover in these suburbs.

We used a similar approach to understand the distribution of irrigated ground covers on nature strips across Darwin suburbs (Figure 35). Nature strips, being public space, can provide a public cooling benefit if irrigated or planted with trees. Ideally, this cooling benefit would be targeted to areas of Darwin with high heat-health vulnerability (Figure 28). Areas with higher proportions of irrigated nature strips were in newer suburbs such as Lyons and Muirhead, and also in streetscapes adjoining green spaces such as Darwin Golf Club, East Point and Rapid Creek. As indicated above, newer areas with fewer established trees have greater amounts of irrigated ground cover (and likely higher water consumption), whereas areas with established trees have lower amounts of lawn and lower water requirements.

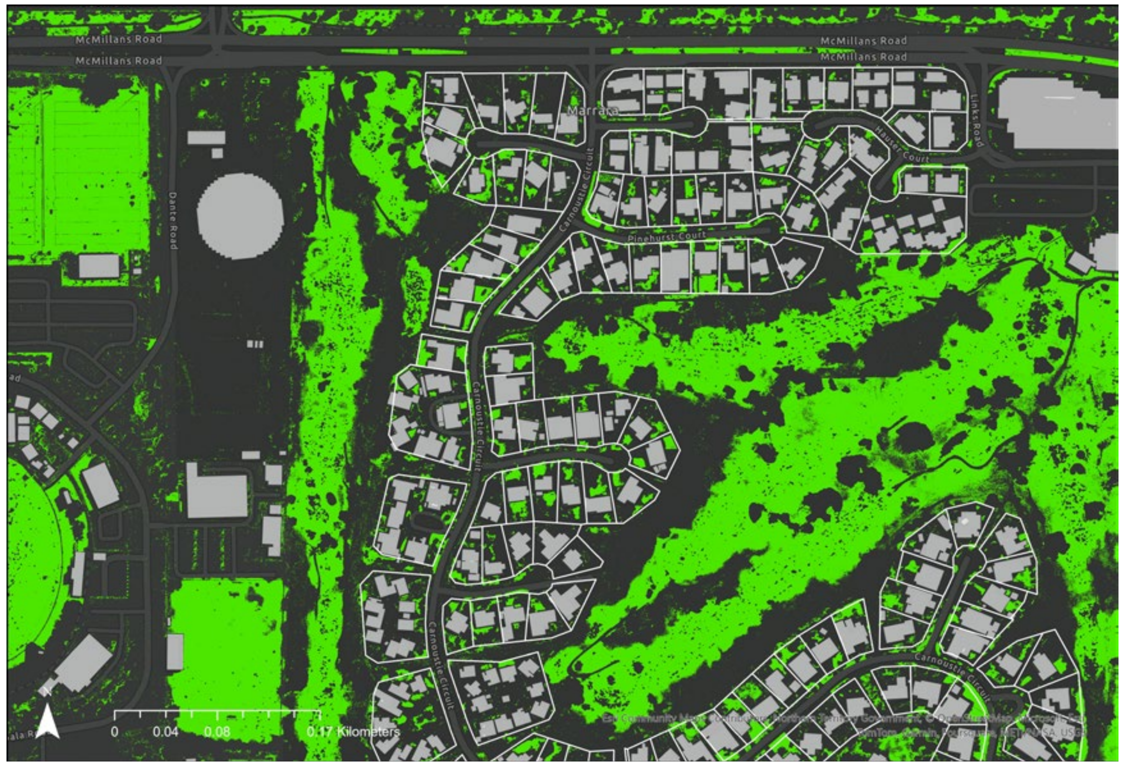


Figure 33. Example of CSIRO Urban Monitor™ classification of irrigated grasses and shrubs at precinct level.

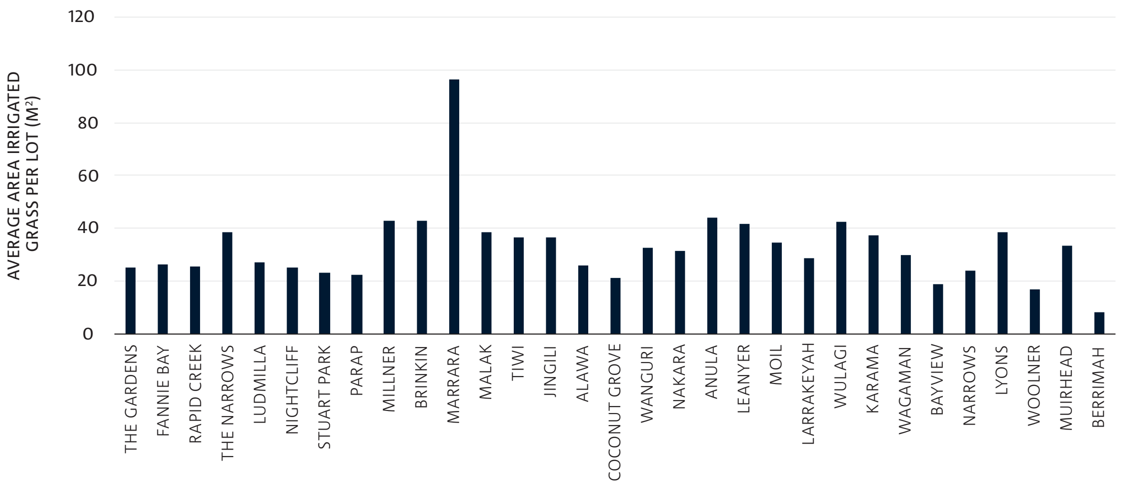


Figure 34. Irrigated ground cover by suburb for single dwelling lots (low-density and low-medium-density residential). Note: analysis excludes very large lots (over 4,000 m2) in Muirhead within the biting insect zone, which were less than 50% developed in 2021.

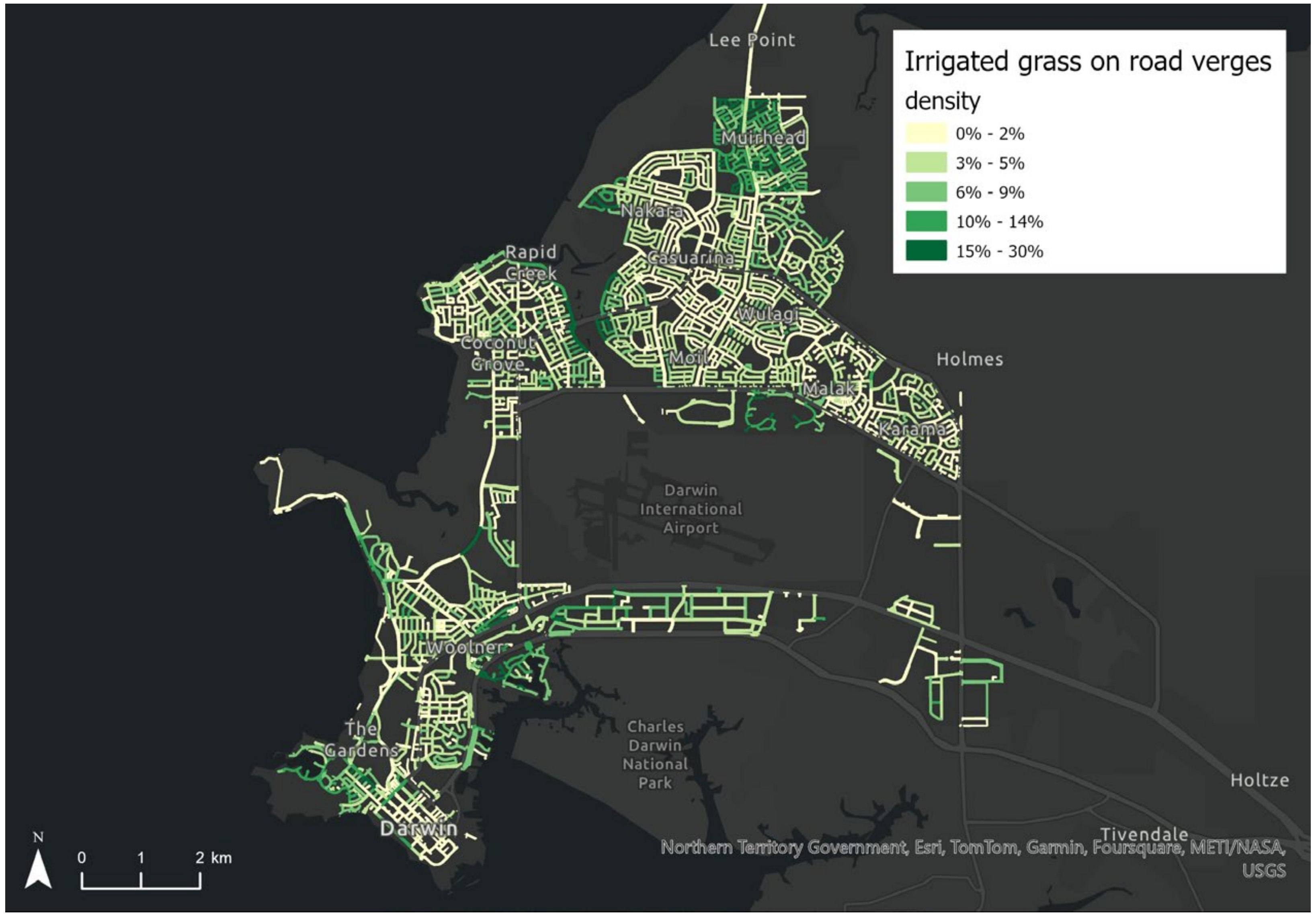


Figure 35. Irrigated grass on road verges (by percentage range).

The use of shade trees and irrigated green space reduces temperatures in urban landscaped areas through shading and evapotranspiration cooling, which improves thermal comfort and can reduce building energy demand. Trees should be prioritised over irrigated grass to deliver public cooling, as trees provide additional shading benefit and require lower amounts of water (as they can draw water up from deep soil longer into the dry season compared to grasses). For example, monsoonal rainforest remains relatively cool throughout the dry season, whereas areas of open eucalypt woodland and grasslands are relatively warmer), due to reduced soil moisture, leading to the drying out and dieback of grasses and groundcover plants, resulting in an increased surface temperature (Figure 11).

Figure 36 shows the areas of irrigated ground cover in 2011, 2016 and 2021. These areas are primarily within public open space, organised recreational space, single dwellings and community purpose sites (including schools). Irrigation patterns appear consistent between 2011 and 2016, but are significantly reduced in 2021; however, this is likely to be influenced by the time of year data were acquired: 2021 data were acquired during the height of the dry season (late July to early August), whereas 2011 and 2016 data were acquired earlier in the dry season – so greater areas of grass are likely to be maintained by higher levels of soil moisture from the wet season.

Darwin's annual mean rainfall, measured at Darwin airport, is 1,723 mm.[58] The annual potential evaporation rate (over open water bodies) in the Darwin region is 1,917 mm[59] and the actual evapotranspiration rate (total moisture from soil and plants) is estimated to average 1,671 mm at the George Brown Darwin Botanic Gardens (Figure 37). Evapotranspiration rates at the Botanic Gardens appear to have increased in more recent years, although it is not clear why. Figure 38 provides a visual image of average actual evapotranspiration rates over the Darwin region (see TERN Data Discovery for further information). Although the annual rainfall and evapotranspiration rates in Darwin are relatively well matched, the lack of rainfall in the dry season requires irrigation to keep up with evapotranspiration rates from April through to November.

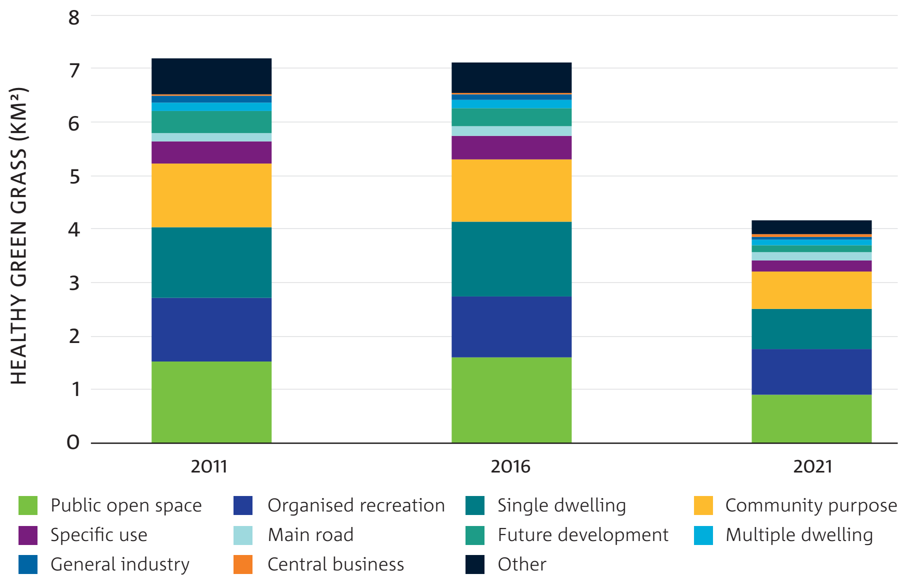


Figure 36. Changes in area of irrigated ground cover in 2011, 2016 and 2021. Excludes conservation areas and areas with no planning control (including the airport and military zones).

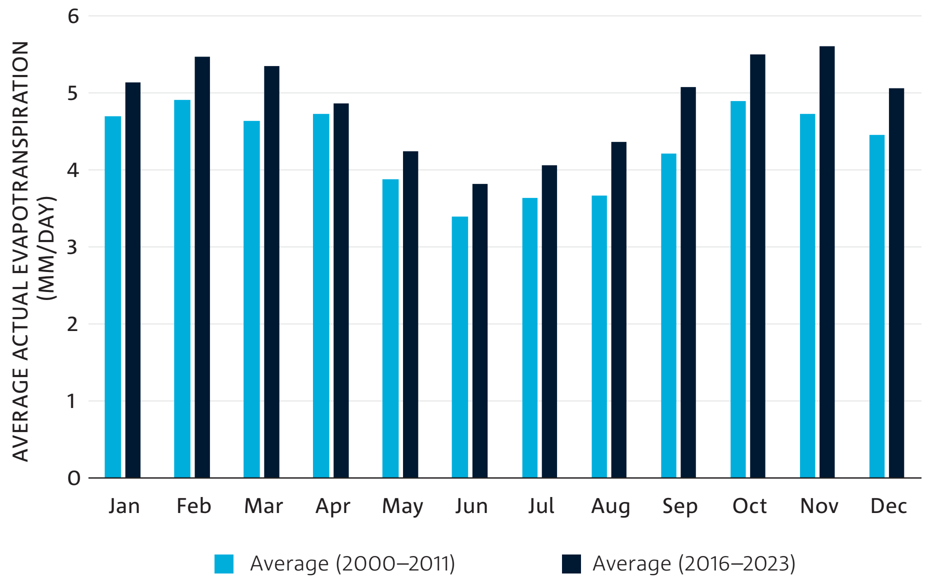


Figure 37. Actual evapotranspiration averaged by month for the periods Feb 2000 – Dec 2011 and Jan 2016 – Nov 2023 for George Brown Darwin Botanic Gardens (Lat: 130.835, Long: –12.4459). Source: TERN CMRSET Actual Evaporation Database.

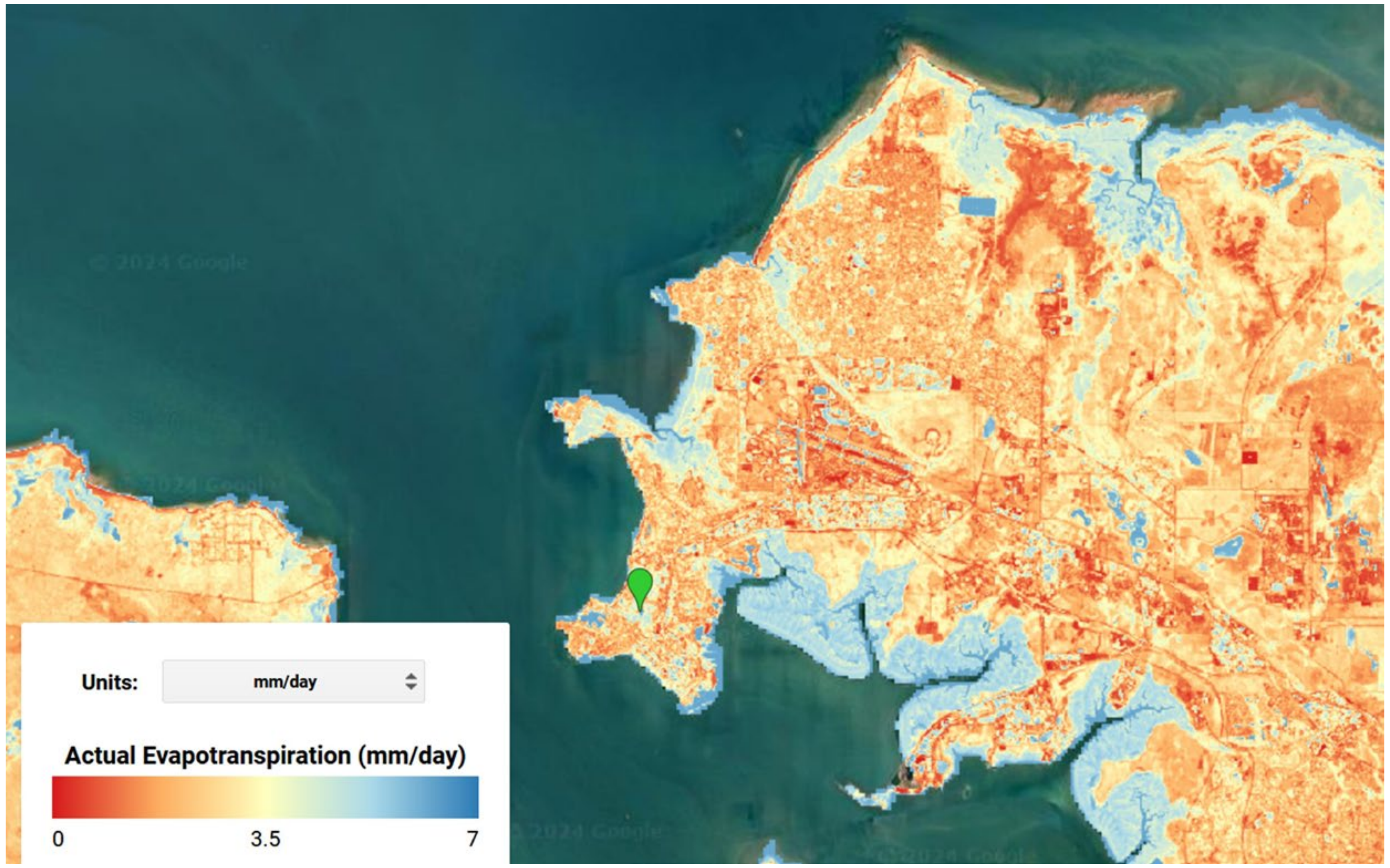


Figure 38. Average actual evapotranspiration (mm/day) over Darwin. Source: TERN dataset (Earth Engine). Creative Commons 4.0. The green teardrop marker indicates the location of George Brown Darwin Botanic Gardens.

58 Climate statistics for Australian locations (bom.gov.au)

59 CSIRO (2018) Water resource assessment for the Darwin catchments. Northern Australia Water Resource Assessment.

Case study – George Brown Darwin Botanic Gardens

The George Brown Darwin Botanic Gardens is one of Darwin's favourite places to visit (Larrakia biodiversity values). It is also one of Darwin's largest users of water (approximately 80 ML per year), with water requirements within four shade houses, 20 ha of gardens, various ponds and a playground water course. A collaboration has been developed between the Botanic Gardens, Power and Water Corporation, NT Office of Water Security and CSIRO to create a better understanding of the water balance at the Botanic Gardens with the view to identifying water-use efficiencies and sharing this learning with other stakeholders (Figure 39).

Climate-resilient water supply

Current urban water systems are subject to a range of challenges relating to rapid population growth, climate change impacts, and water infrastructure that is ageing and reaching capacity constraints. There is significant investment in securing Darwin's water future by increasing supply – for example, through returning Manton Dam to service as a water source, and through the Adelaide River off-stream water storage project (AROWS). There is also the need to explore demand-side approaches and using water more effectively within the urban landscape. The uptake of water-sensitive urban design approaches in Darwin has been limited to this point with no mandated performance targets included in the development process. There has also been a lack of water efficiency measures and very limited water recycling. This in part has been influenced by the perceived lack of necessity, with the view that water is plentiful and low cost. However, it has been recognised in the recently released NT Strategic Water Plan that there are opportunities for exploring innovations in water management. The plan recognises the value in examining barriers and incentives, and establishing trials for more water efficient practices that can support sustainable growth in the Territory.

Conventional approaches for managing water in cities focus on delivering a safe drinking-water supply, the efficient collection and disposal of wastewater to protect human health, and the mitigation of urban flood risk. In recent decades, there has been a growing understanding of the need for cities to develop cost-effective and socially acceptable climate-resilient water supplies, and for urban planners and developers to also consider the implications for maintaining and restoring pre-development hydrology and nutrient cycles, and to provide improved amenity (i.e. cooling, greening, recreational use and biodiversity outcomes).

A warmer future climate is projected to intensify the effects of heavy rainfall and fire events in Darwin and surrounding areas.[60] Heavier rainfall events could strain water infrastructure, causing flooding and supply contamination. Increased fire activity could degrade water quality due to ash and sediment, necessitating extra treatment. Extended dry seasons or droughts are also possible, which may deplete reservoirs and groundwater, affecting urban and agricultural water supply.

Figure 39. CSIRO monitoring of soil moisture and environmental conditions at George Brown Darwin Botanic Gardens.

Figure 40. Tree pit in Austin Lane. Stormwater is able to flow from the pavement into the tree pit and excess water is able to overflow.

Water-sensitive urban design

'Water-sensitive urban design' approaches to urban design and planning can help to mitigate impacts of urban development in cities, including reducing the urban heat island effect. These approaches can help to retain water in the landscape and support natural flow-paths and infiltration of stormwater runoff. Design features such as raingardens with tree pits, swales and pervious pavements can help support healthy vegetation, that can in turn improve thermal comfort in cities through direct shading of people and urban surfaces, while enhancing cooling benefits of evapotranspiration (Figure 40).

While retaining stormwater in the landscape can benefit cooling and greening, it can also lead to challenges with biting insects if water-sensitive urban design approaches are poorly conceived or implemented. Trunk drains are typically installed to ensure there are no shallow ponds or swamps that attract such insects.

A risk averse approach to stormwater design is to manage flooding with detention basins that hold water for only a few hours. Where water is held for longer, NT Health Entomology[61] advice is critical to informing design approaches such as ensuring water bodies have steep edges and are deep enough to retain fish (which eat mosquito eggs). Keeping nutrient levels low and the use of water agitation are also useful strategies, as is regular maintenance of surrounding vegetation.

Rainwater tanks, a common water-sensitive urban design feature in climates with regular rainfall, are not readily used in Darwin's unique climate because storage volumes are small and once used at the start of the dry season, they remain idle and add limited value (and they also need to be carefully managed to avoid mosquitoes).

60 NT Government, 2020. Climate Change in the Northern Territory – State of the science and climate change impacts

Wastewater treatment

Darwin Harbour water quality reports show that the poorest quality water is regularly observed in Buffalo Creek and Myrmidon Creek – both of these creeks are affected by the release of treated water from urban Leanyer Sanderson and Palmerston waste stabilisation ponds.

Water quality can be improved by moving to higher levels of wastewater treatment, although 'tertiary treatment' comes at a cost.[62] But higher levels of treatment enables recycled water to be used safely for irrigation, and provides a climate-independent source of water.

In the dry season, a small amount of recycled water is pumped to the Northlakes Reuse Plant for additional treatment before being used for irrigation at the Darwin Golf Course and Marrara sporting ovals. Many large water recycling schemes are operational in other Australian states and territories.

Future developments and opportunities

Opportunities to increase water storage are limited (due to the relatively flat terrain of Greater Darwin) which means that perennial rivers are vital assets for Darwin. There are opportunities for groundwater development, but more data are required to determine extraction limits.[63] The newly released NT Strategic Water Plan is mandating water efficiency targets for all NT Government agencies in the Greater Darwin area. As a result, new approaches to efficient water management and water use will be needed, such as digital metering to understand usage patterns and to identify leaks. Power and Water Corporation's Living Water Smart initiative has tools and information to enable water saving measures through improved irrigation and metering of large water users.

Increased uptake of water-sensitive urban design approaches through urban planning and renewal should be considered. There is a need to increase local knowledge of how to do water-sensitive urban design for Darwin, noting the combined benefits that are offered in cooling and greening the city, while reducing the demand on drinking-water supplies.

Data from this study have shown that tree planting provides more cooling than irrigated grass, and may also decrease the water needed to keep Darwin 'green' all year round.

Recycled water schemes are part of securing climate-independent water sources for the wider NT (and form part of the NT Strategic Water Plan). For Darwin, although its annual rainfall is high, deficits in evapotranspiration can occur for 9 months of the year; therefore, return on investment for water recycling is likely to become increasingly attractive as the population grows and water storages struggle to meet demand.

61 NT Department of Health (2023) Constructed Wetlands in the Northern Territory, Guidelines to Prevent Mosquito Breeding. Medical Entomology Centre for Disease Control.

62 NT Government: Code of Practice for Wastewater Management

63 CSIRO (2018) Water resource assessment for the Darwin catchments. Northern Australia Water Resource Assessment.

04 Sustainability: Towards Net-Zero

As greenhouse gas (GHG) emissions accumulate in the atmosphere, the earth's climate continues to trend towards hotter and more intense weather. Darwin is particularly susceptible to climate change due to increasing heat, more frequent and severe storms and flooding, and sea level rise.[64]

The more intense weather events are likely to damage critical infrastructure, place pressure on biodiversity and exacerbate public health concerns.[65] There is a need for Darwin to reduce GHG emissions while making changes to prepare for its future climate. Federal, Territory and local government policies are aligned in progressing climate adaptation and aim to achieve net zero emissions by 2050, 2050 and 2040, respectively. In addition, various measures are being implemented, such as increasing renewable energy supply, improving water management, enhancing coastal defences, promoting biodiversity conservation and developing community resilience plans. The success of these measures, and in achieving a net zero emissions Darwin, will rely on the collaboration and engagement of all stakeholders, including the government, businesses, communities and individuals.

What do we currently know about emissions in Darwin?

There are several GHGs, and some gases have a stronger effect than others. In practice, the contribution of all GHGs is evaluated as carbon dioxide equivalent (CO_2e) units. National tools have been developed to estimate localised GHG emissions, and average annual emissions for Darwin were around 1.43 million tonnes of CO_2e from 2018 to 2021 (Figure 41).[66] Electricity was the largest contributor, accounting for 38% of total emissions, followed by gas (28%) and transport (20%). Waste contributed 9%, while industrial processes and product use generated 5% of total emissions. Gas emissions reported in Figure 41 are those estimated to be linked to industrial jobs within the NT. To balance LGA and Territory emission accounting, elevated gas industry emissions are associated with the Darwin LGA. Mining operations in the gas sector accounted for 18% of Darwin's GHG footprint. The aviation industry and automotive use generated 13% and 7% of the city's annual GHG, respectively. Each industry sector has a role to play in adopting low emission technologies and supporting the energy transition.

Embodied carbon emissions are not included in the data used in Figure 41, and therefore form an additional component. From 2021 data, the Darwin Living Lab estimates the construction materials in residential, commercial and industrial buildings to be about 15.1 million tonnes, which corresponds to about 7.5 million tonnes of CO_2e (Table 4). The information below discusses and explores opportunities to reduce emissions from electricity, transportation and waste, and a detailed case study on embodied emissions is given.

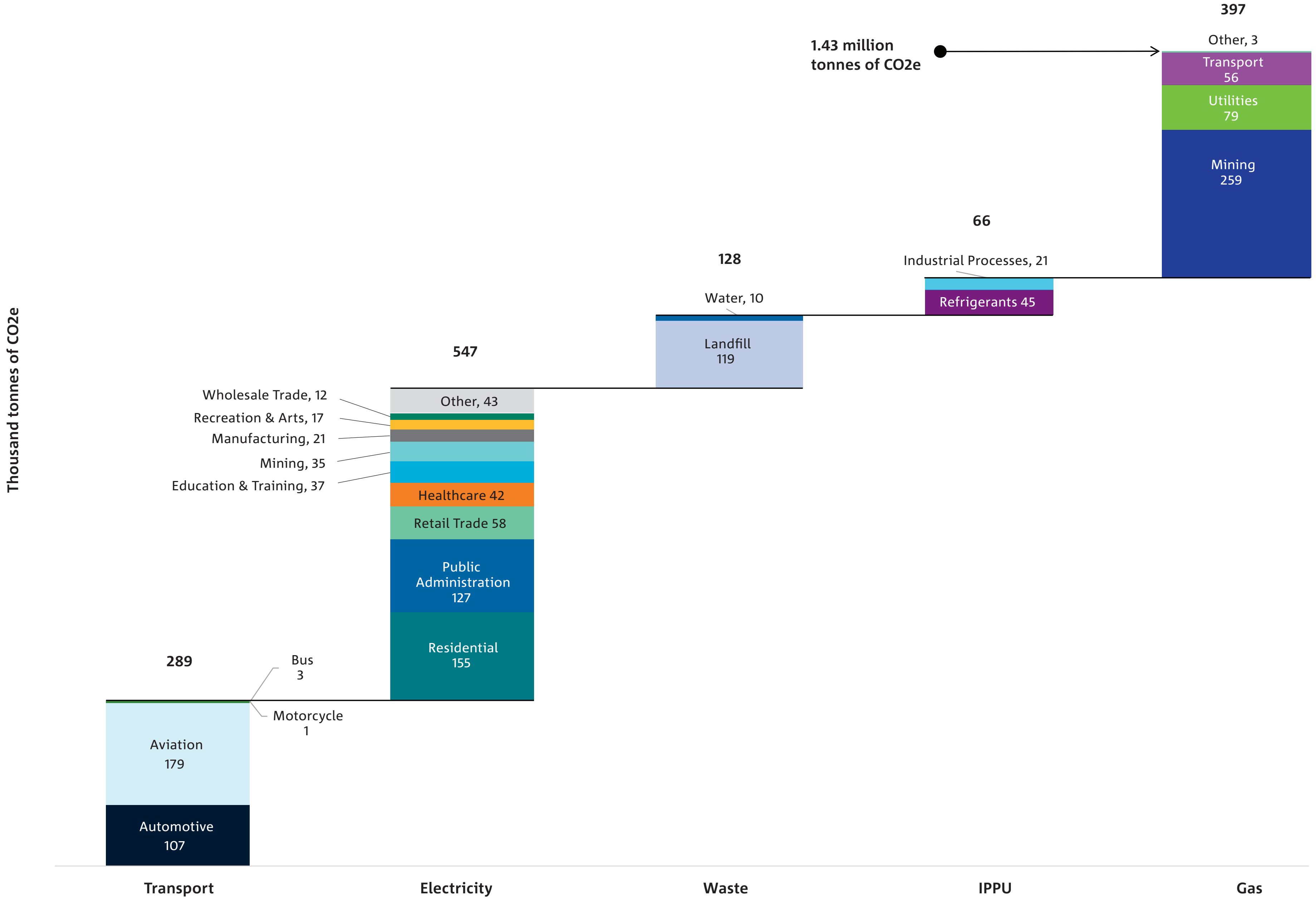


Figure 41. Average CO_2e emissions per sector (2018–2021). Data source: 2022 Snapshot emissions profile – Ironbark Sustainability and Beyond Zero Emissions. Emissions include those emissions from industrial processes and product use activities; emissions and removals from agriculture, forestry and other land use; Scope 3 emissions from stationary energy; and emissions from transboundary transportation.[67] Note: Bold numbers indicate total emissions per sector (https://snapshotclimate.com.au/user-guide/).

64 NESP Earth Systems and Climate Change Hub. 2020. Climate change in the Northern Territory: state of the science and climate change impacts. NESP ESCC Hub, Melbourne.
65 Field and Barros (2014) Climate change 2014 – impacts, adaptation and vulnerability: regional aspects.
66 Ironbark Sustainability & Beyond Zero Emissions (2022)
67 For more information about the methodology applied see https://snapshotclimate.com.au/media/jc_media/2022/12/22/CIU_SNP_005_Methodology_v1a.pdf.

The impact of economic and population growth

GHG emissions are generally linked to economic and population growth. With a higher population and increased economic activity, there is greater purchasing power and consumption of goods and services, which typically results in a larger emission footprint. Population and economic expansion impacts the demand for infrastructure – such as buildings and housing, roads and transportation, and energy and services – which have long-lasting effects on urban emissions.

Darwin's gross regional product increased from $8.4 billion to $12.7 billion from 2012 to 2022 (Figure 43), despite an economic slowdown during the COVID-19 pandemic. With slow population growth, gross regional product per capita increased by 44% in the same period. The employed population grew from 39,000 in 2011 to 52,000 in 2021 – a 34% increase. Public services, and health care and social assistance, account for the largest share of employment across industries in Darwin (Figure 42). The number of jobs in financial and insurance services, information management and technology, wholesale trade and manufacturing decreased between 2011 and 2021. The largest increases in employment occurred in agriculture, forestry and fishing, health care and social assistance, and construction. Changes in public sector emission intensities are likely to have a significant impact on Darwin's emission footprint.

Urban expansion and intensification to accommodate the needs of a larger population and a growing economy will have direct impacts on emissions. According to the Greater Darwin Plan Territory 2030,[68] the demand for development within the City of Darwin would require up to 9,500 new residential dwellings, 121,500 m^2 of retail area, 84,100 m^2 of office/commercial area, and 390 ha of industrial land. Although these projections are likely to be outdated, they highlight the implications of urban land planning decisions and signal future growth in both embodied and operational emissions for Darwin.

Demographic variables within the population could also influence Darwin's emissions – for instance, gradual shifts in consumption preferences due to changes in age composition or domestic and international migration.

The materials and energy required to maintain and expand Darwin's built environment to accommodate the needs of a growing population and economy could have large and long-lasting implications for the city's carbon budget.

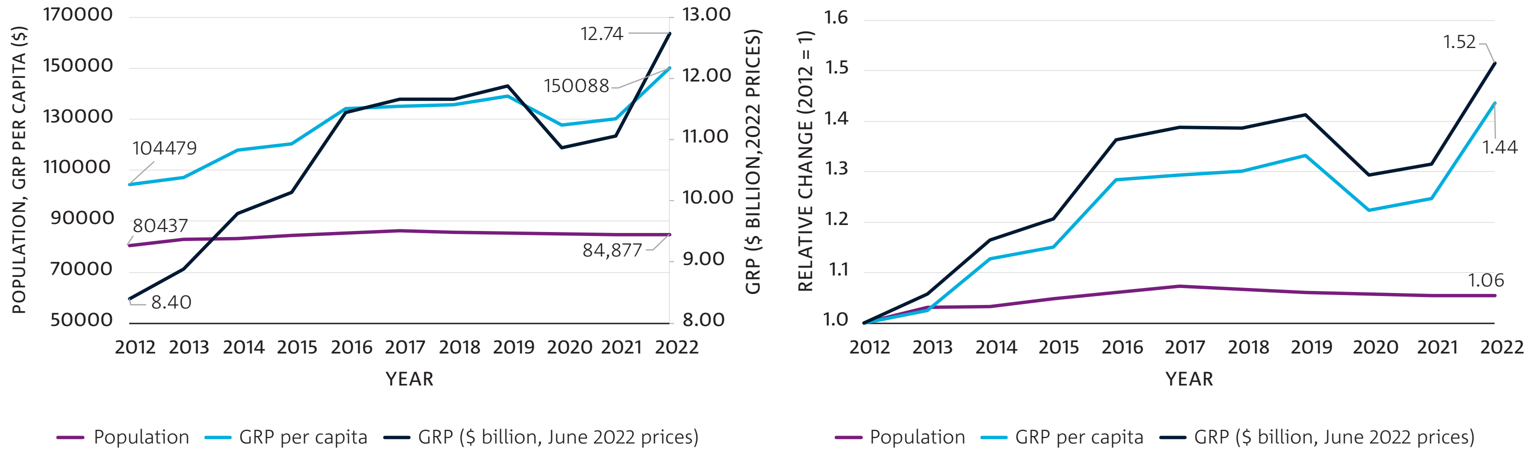
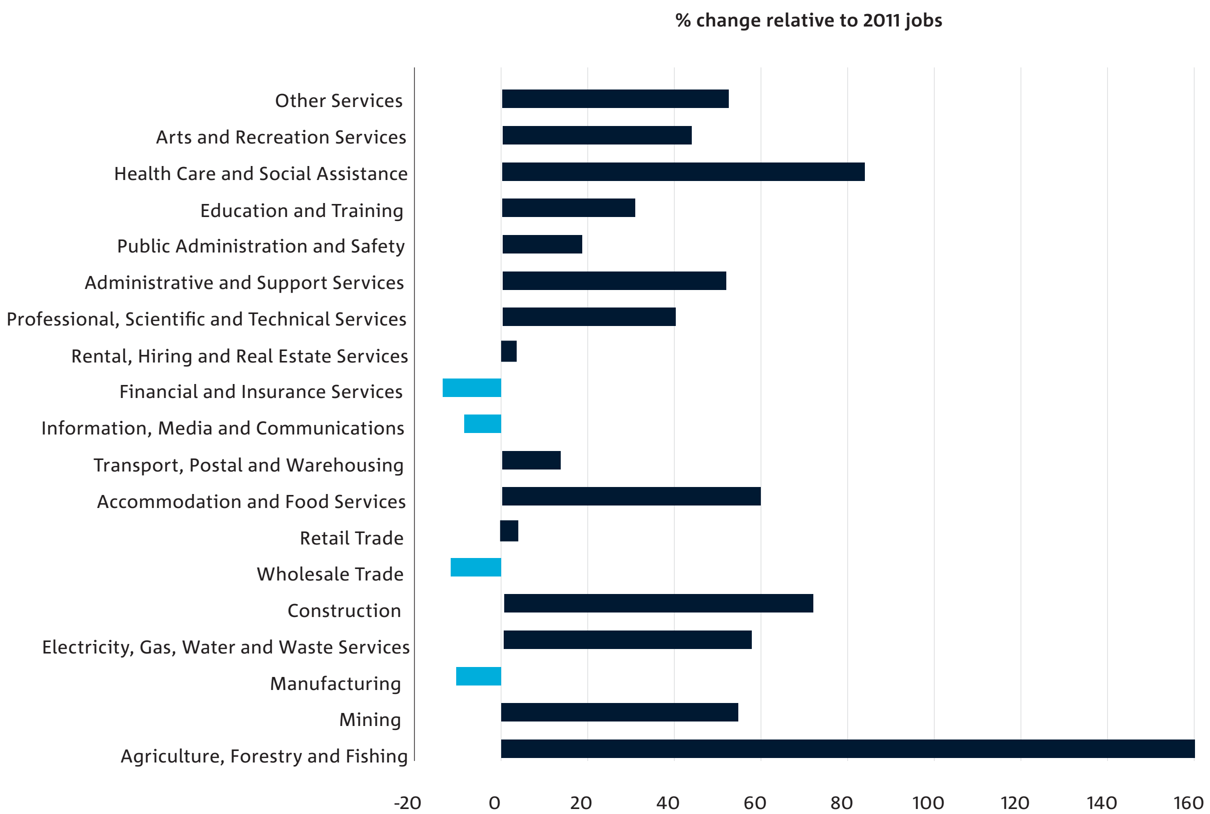


Figure 42. Gross regional product (GRP) and population change 2012–2022: (left) change in gross regional product and population, (right) relative change 2012 = 1. Data source: https://app.remplan.com.au/darwin/economy/trends/jobs?state=OQG6cN!vR6PCDwAzSOOJeNF4JWOdtpcNHp7yUrHwHdlt4HzIKKgDud2j.



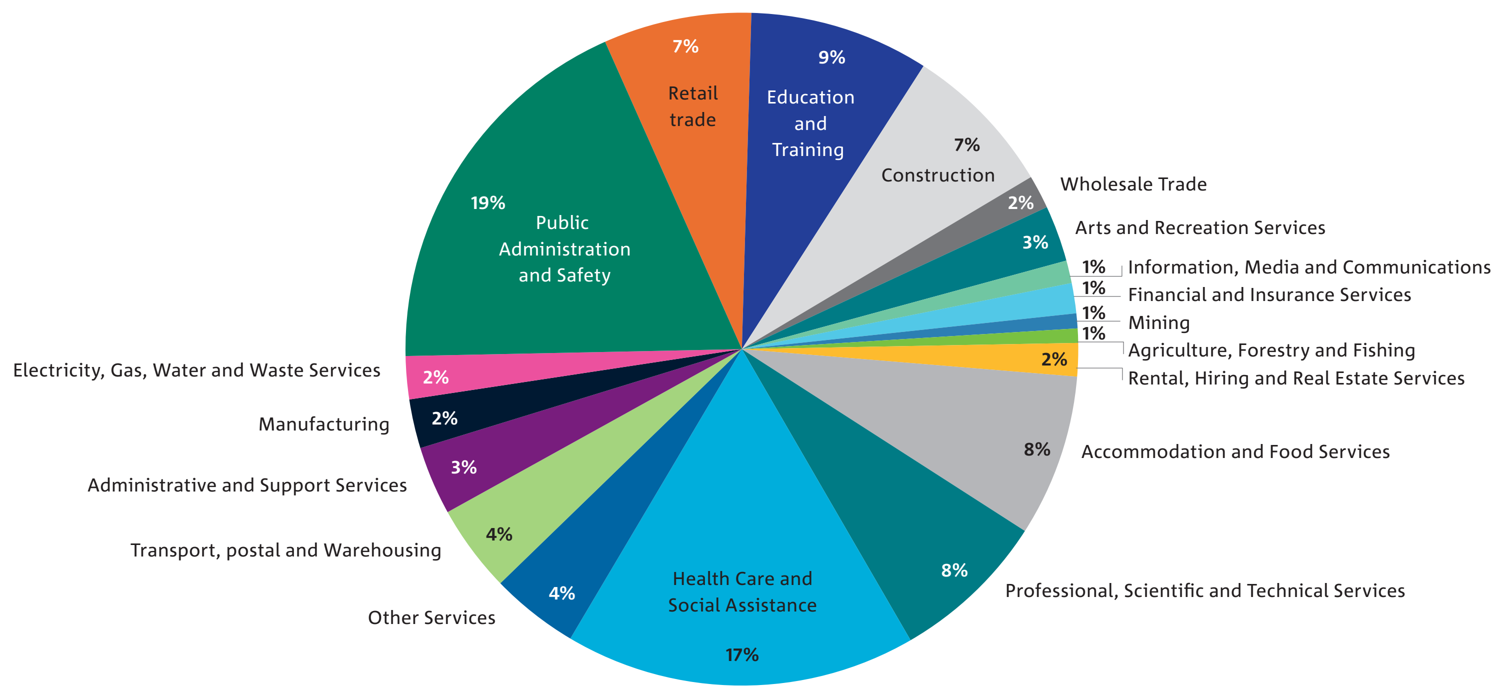


Figure 43. Left: employment change by sector 2011–2021. Right: employment by sector in 2021. Data source: https://app.remplan.com.au/darwin/economy/trends/jobs?state=OQG6cN!vR6PCDwAzSOOJeNF4JWOdtpcNHp7yUrHwHdlt4HzIKKgDud2j.

68 NT Government (2012) Greater Darwin Plan.

Climate change creates additional challenges for emissions reduction

Higher average temperatures and more frequent and intense heatwaves in Darwin is likely to increase demand for cooling (see 05 Indoor Liveability), leading to higher energy consumption and emissions. Resources needed to repair or replace damaged infrastructure from extreme weather events or to prepare for climate change impacts could also increase city emissions.

Cyclones Tracy and Marcus demonstrated the impacts that extreme weather events can have on emissions. Cyclone Tracy had a devastating effect both on built and living infrastructure, and rebuilding and renewal required using new materials with significant embodied emissions. The loss of around one third of Darwin's tree canopy cover in 2018 from Cyclone Marcus also had emission implications. There was a loss of capacity for trees to store carbon as biomass, a loss in annual carbon sequestration and a reduction in the cooling effect of trees.

Climate-induced supply chain disruptions could also increase the energy and emissions needed by city residents and industries for transporting resources.

Opportunities for electricity generation and the role of buildings

Primary energy use in the NT in 2020–21 was from gas (74.4%) and oil (24.7%), with renewable energy only accounting for 0.9%.[69] In contrast, the national share of renewable energy use was 7% during this period. In transitioning the electricity grid to renewable energy, care is needed to manage both energy cost and electricity grid stability.

Solar photovoltaics (PV) plays an important role in allowing buildings to provide liveable and sustainable indoor environments. When the sun shines and it is hot, the renewable energy generated can be used directly to run air conditioners. A Darwin Living Lab-associated collaboration between Charles Darwin University, CSIRO, City of Darwin and ARENA evaluated opportunities for improving the value of onsite renewables by connecting three Darwin buildings to the iHub Data Clearing House to provide real time data and optimise performance.[70] The project identified opportunities for existing building stock to host increased solar PV, reduce energy consumption and improve maintenance scheduling. Making buildings smarter provides multiple benefits, including energy-efficiency savings of about 10% and enabling dispatchable energy (on demand) at less than 20% of the cost of electrical batteries.[71]

Despite high solar radiation levels, the NT overall has a lower uptake of solar PV compared to other Australian jurisdictions; however, in Darwin the uptake is quite strong. Data from the Australian PV Institute accessed in December 2023 estimated there to be 7,433 solar PV installations across the Darwin LGA, and that around 33% of dwellings have solar PV. This compares to 43% in Brisbane and 7.4% in the City of Sydney LGA. The total capacity of small (<10 kW) residential systems in Darwin is estimated to be 39,319 kW, providing approximately one and a half times the capacity of larger (>10 kW) commercial systems (27,057 kW).

In 2021–2022, the Darwin node of the Darwin-Katherine electricity grid had an average consumption of about 150 MW and a maximum demand of 256 MW, with a peak demand no longer occurring mid-afternoon, but shifting into the evening due to increased levels of solar generation during the middle of the day.[72] Despite the investment in renewable energy, the vast majority of grid energy is sourced from gas generation.[73]

Integrating renewable energy into the electricity grid creates new challenges in managing grid stability. Distributed battery storage is at the centre of the NT Government's Darwin-Katherine Electricity System Plan and includes incentivising battery uptake in homes and businesses, as well as investment in larger-scale batteries to underpin a cleaner, more affordable and secure energy system. The opportunity exists for new homes and buildings to incorporate design to support the greater electrification of transport (e.g. EVs), such as with additional solar and EV battery integration with buildings.[74] It is worth noting that 'behind the meter', commercial building operators do not solely rely on batteries to balance electricity loads and achieve efficiencies – for example, the use of thermal storage (i.e. chilled water) can deliver cooling at reduced cost and increase flexibility in grid demand.

69 Australian energy mix by state and territory 2020–21 | energy.gov.au
70 Thennadil et al. (2002) Increasing the value of onsite renewables in Darwin through data driven analytics.
71 Scoping the Digital Innovation Opportunity for Energy Productivity in Non-residential Buildings (dcceew.gov.au)
72 2022 NT Electricity Outlook Report
73 Australian Energy Update 2022
74 Microsoft Word – CSIRO EV report_20221124.docx (aemo.com.au)

Opportunities for improved transportation

The ABS census in August 2021 (dry season) determined that 74% of Darwin residents travelled to work by car (90% of these trips as the driver), 7% by active transport (65% walking and 35% cycling) and 4% by public transport (95% by bus), and 13% worked from home.[75] By comparison, in 2016, 73% travelled to work by car, 8% by active transport and 7% by public transport, and 10% worked from home. The reliance on private car transportation increases pressures on emission reduction targets, while sprawling urban growth patterns continue to increase dependence on private transportation.[76]

Passenger and light commercial vehicles in Darwin are almost all fossil fuelled (99.9%), with 46,286 petrol vehicles and 25,093 diesel vehicles.[77] The NT currently has the lowest uptake of EVs in Australia, with EVs being only 2.4% of new vehicle sales in the Territory in 2022.[78] In 2021, there were only 70 EVs registered to Greater Darwin postcodes. The NT also has the highest proportion of passenger and light commercial vehicles that are SUVs, which make up more than 30% of the fleet compared to 25.3% nationally.[79] SUVs offer more space and greater ability to drive on 'unmade' roads, but are generally less fuel efficient and emit more GHGs than medium-sized passenger cars.

Figure 44 shows that active transport is most frequently used in Darwin for trips to work that are 10 km or less. Bike is the predominant active transport mode for commutes between 2.5 and 10 km, and walking for commutes less than 2.5 km. Figure 45 shows that the median distance to work is the least in suburbs around the Darwin CBD, which also has the highest rates of active transport. In addition to reducing emissions, using active transport can reduce transport costs for Darwin households; transport costs are estimated to be 17.1% of the income of a typical Darwin household, slightly more than the estimated average of 16.9% across all capital cities.[80] While SUVs may offer greater freedom to explore Darwin's natural surrounds, EVs are a suitable option for Darwin's high number of short commutes and day-to-day trips.

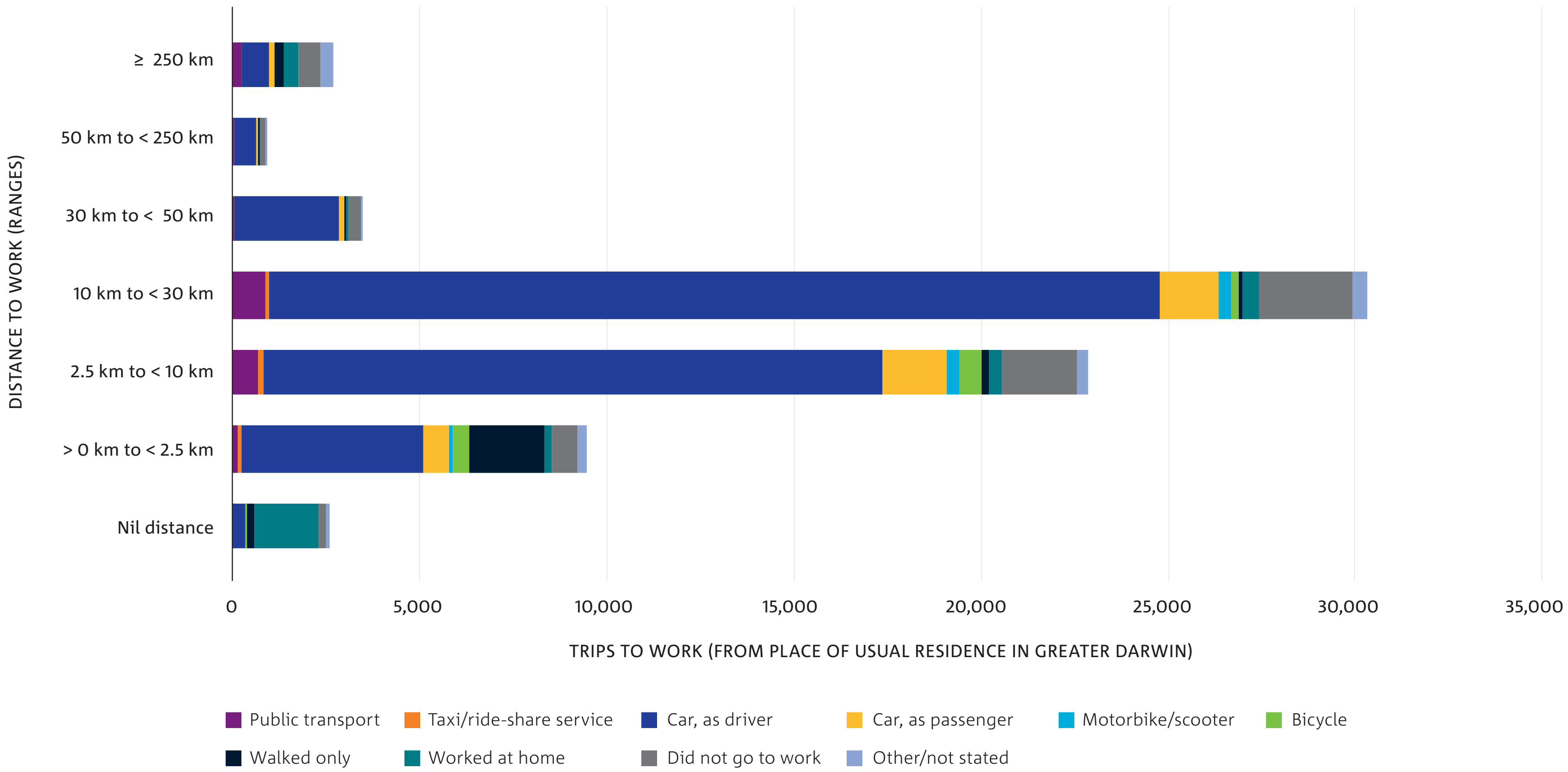


Figure 44. Mode of travel to work by distance range (Greater Darwin). Source: ABS 2021 Census of Population and Housing.

75 ABS Census 2021. Census of Population and Housing, 2021, TableBuilder
76 Kavaarpuo, G et al. (2022). Darwin: Towards the sustainability of the Larrikin of Australian capital cities. https://doi.org/https://doi.org/10.1016/j.cities.2021.103457
77 ABS 2021 Motor Vehicle Census
78 Electric Vehicle Council. (2023). State of Electric Vehicles – July 2023.
79 Australian Government, BITRE (2021) Most popular light vehicles in Australia – a regional perspective (Information Sheet 108)
80 Australian Automobile Association. (2023). Transport Affordabilitity Index – September Quarter 2023.

A potential barrier to increased levels of active transport is Darwin's climate – particularly the high humidity and rainfall during the build-up and wet season.[81] Bike counter data for the Daly Street bike path show that average bike traffic is higher in the dry season, with an average of 136 daily bike rides in the driest months (Jun–Aug) compared to 100 in the wettest months (Jan–Mar).[82] Despite the decline in cycling rates in the wet season, cycling remains a popular choice suggesting that, like most transport choices, cycling becomes a habit.[83] However, bike counter data for the Daly Street bike path indicate an overall annual decline in average daily bike rides, from 166 in 2014 to 107 in 2022. Female participation in cycling is often used as an indicator of network accessibility or inclusiveness.[84] The 2023 'Super Tuesday' bike count found that 31% of cyclists in Darwin were female compared to the national average of 25%.[85]

The City of Darwin 2030 Movement Strategy aims to improve urban mobility and mitigate environmental impacts by improving streetscapes, infrastructure and connectivity. It outlines measures to upgrade and prioritise pedestrian and cycling infrastructure, and to embrace emerging forms of electric micromobility such as gophers, e-scooters and e-bikes (noting that these modes need to be used safely). The Darwin CBD is evolving to support improved and safer movement by reducing speed limits to 40 km/h and exploring trade-offs – for example, between areas needed to support shade trees and areas designated as parking spaces.

Effective public transport systems can help to reduce GHG emissions by offering an alternative to car trips with only one or two people. However, public transport use in Darwin is the lowest of all Australian capital cities. City of Darwin research has shown existing services are perceived to be inefficient and unattractive. Efforts to improve bus services include a focus on frequency, safety and cleanliness. In addition, a free central Darwin shuttle bus is being considered, to change local perception and improve the experience of visitors to Darwin.

Aviation emissions are estimated to be greater than automotive emissions (Figure 41); however, being relatively isolated from other cities and destinations, it is important for the residents of Darwin to have access to air travel. Change is required within the aviation industry to meet this challenge, and there are several initiatives seeking to reduce aviation emissions, such as the transition to renewable biofuels, voluntary passenger offset schemes and air-traffic management efficiencies.[86]

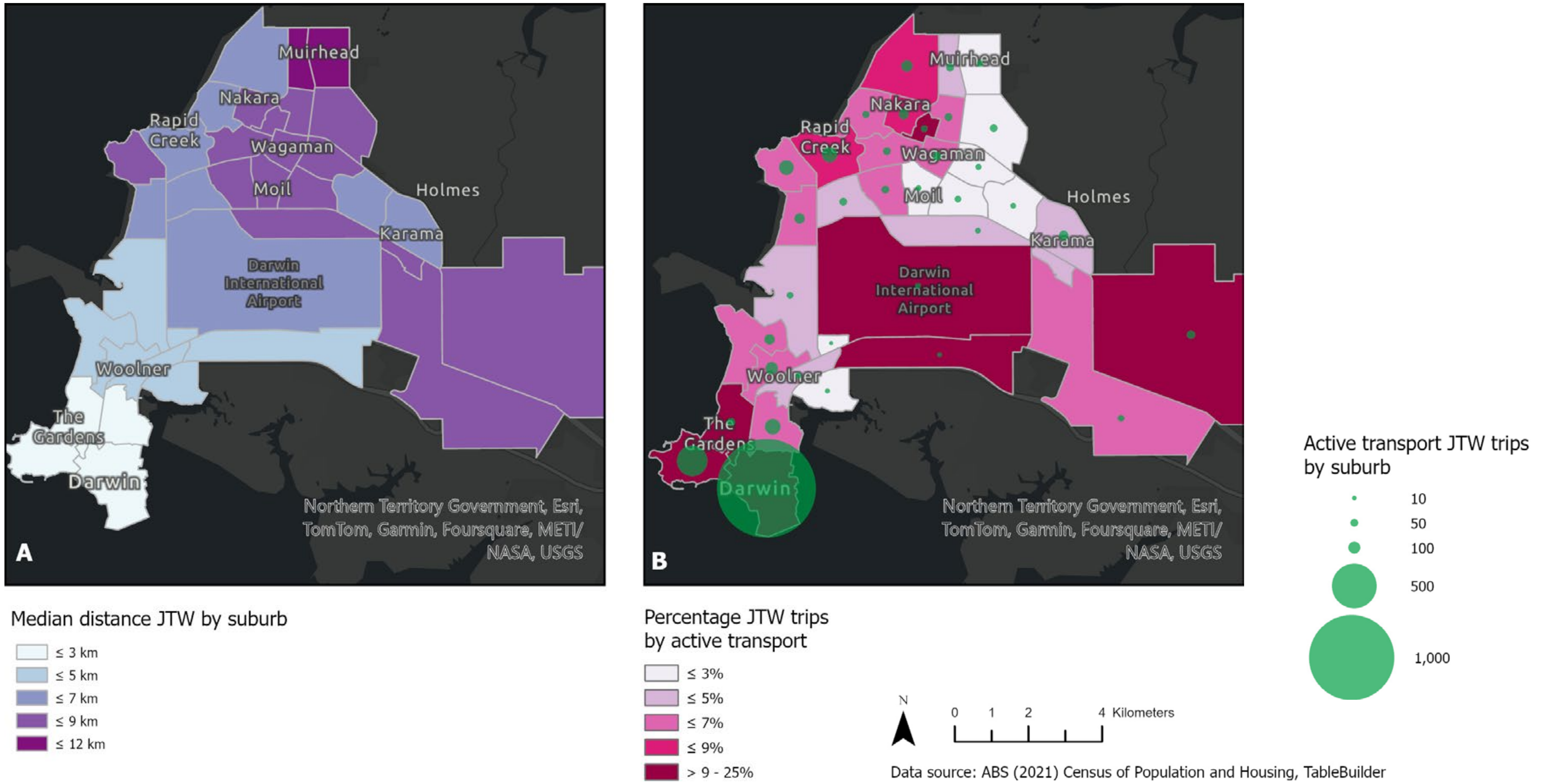


Figure 45: Journey to work (JTW) by suburb: (a) median commute distance, (b) trips by active transport modes.

81 Cruikshank J (2018) From heritage to hi-tech–a shared path story. Australasian Transport Research Forum (ATRF), 40th, 2018, Darwin, Australia.

82 DIPL (2022) Annual Traffic Report. NT Government.

83 Fu X (2021) How habit moderates the commute mode decision process. https://doi.org/10.1007/s11116-020-10144-6

84 Heesch et al (2012) Gender differences in recreational and transport cycling: a cross-sectional mixed-methods comparison of cycling patterns, motivators, and constraints. https://doi.org/10.1186/1479-5868-9-106

85 Bicycle Network (2023) Super Tuesday Top End Bike Count – Darwin: July/August 2023

86 Aviation emissions | Department of Infrastructure, Transport, Regional Development, Communications and the Arts

Opportunities for the transition from waste to a circular economy

Estimated GHG emissions associated with waste in Darwin are significant and at the same order of magnitude as road-based-transport emissions (Figure 41). According to the National Waste Database 2022, 89% of waste generated in the NT ended up in landfill, 10% was recycled and 1% was used for energy recovery.

Total waste from 2020–21 in the NT was 344,174 tonnes – 1.48 tonnes per capita (substantially lower than the national average of 2.95 tonnes per capita). Municipal solid waste accounted for 43% of annual waste flows, commercial and industrial waste accounted for 38%, and construction and demolition waste accounted for 19%. Darwin's per capita waste generation is similar to Territory wide rates. In 2019–20, the Shoal Bay facility, which services the entire Greater Darwin region received 200,600 tonnes (1.47 tonnes per capita). In the same year, 68,700 tonnes (33.5%) of all waste was recycled, comprising organics (38.8%), masonry and concrete (26.4%), metals (17.2%), cardboard and paper (11.7%), glass (3.8%), tyres (1.1%), plastics (0.7%) and e-waste (0.3%). The NT has the lowest waste recovery rate in the country, but recycling in the Greater Darwin area is improving, and emissions reductions are being achieved through the management of organic waste.

Renewed efforts are being made through NT Government and City of Darwin strategies to lower waste generation and increase recycling rates. The city has instituted various initiatives, such as kerbside collection of recyclables and organic waste, and increased use of recycled materials. Key initiatives at the Shoal Bay Waste Management Facility are a mulch sales facility, concrete crushing for onsite reuse and a landfill gas facility to convert captured methane to renewable energy (approximately 750 MWh of energy per month).

Darwin Living Lab modelling (see the case study below) suggests that there is almost 10 million tonnes (10 Mt) of concrete within the build environment in Darwin, followed by sand and stone (2.54 Mt), steel (0.95 Mt) and ceramics (0.89 Mt). Concrete is estimated to contribute around 15% of landfill at Shoal Bay.[87]

Steps are being taken to advance the circular economy through the recycling of concrete. For example, the NT Government has provided permission for the Ostojic Group to use blended road pavement material that includes recycled concrete. Construction company NTEX has introduced pre-demolition audits to identify recycling routes for different materials; over 2 years, it has averaged 93% recyclability over 18 projects. Circularity not only improves material and emission outcomes – it creates jobs. The recycling industry in Australia has demonstrated that it creates around three times as many jobs than the equivalent employment if waste is sent to landfill.[88] Greater recycling in Darwin is also an opportunity to decrease dependence on external imports, which are costly and have associated transport emissions.

87 City_of_darwin_concrete_factsheet_06.pdf (nt.gov.au)
88 A circular economy roadmap for plastics, tyres, glass and paper in Australia – CSIRO

Case study – Embodied emissions in Darwin's buildings

As Darwin continues to grow and renew, demand for building materials will continue to rise. Meeting the net zero target will require transformative changes to how cities are constructed. In the absence of accurate information on embodied emissions in building materials and their environmental impacts at the city scale, the Darwin Living Lab used Urban Monitor™ datasets generated in 2016 and 2021, building archetype information and statistical models to estimate the embodied emissions in materials in buildings in the Darwin LGA, and their energy, carbon and water footprint (Figure 46).

In 2021, there were around 26,102 buildings in Darwin, categorised as single-family homes (79.5%), twin homes (13.1%), business premises (2.7%), apartments (1.3%), public amenities (1.4%), industrial buildings (1.1%) and specialised edifices (0.9%). The combined gross floor area for these structures was an estimated 77 km^2, occupying a land mass of approximately 43 km^2. The gross floor area mainly comprised single-family homes (56%), followed by twin homes (17%), business premises (12%) and public amenities (5%). The remaining categories, encompassing apartments, industrial sites and specialised buildings, contributed to 11% of the total gross floor area.

Materials used to construct buildings in Darwin have a total weight of around 15.1 million tonnes, resulting in 0.75 tonnes of material per m^2 of gross floor area. Those materials required around 7.5 million tonnes of CO_2e emissions to be produced and consumed an estimated 100,000 TJ of energy and 135,000 ML of water in their manufacture.

Figure 46. CSIRO Urban Monitor™ three-dimensional building layer for Darwin overlaid onto the ground layer.

Table 4. Building material stock and embodied environmental impacts in buildings in the Darwin LGA, 2021.

MATERIALS	MATERIAL STOCK (TONNES)	PERCENTAGE OF MATERIAL STOCK	ENERGY (TJ)	WATER (ML)	GHG (TONNES OF CO_2E)	GHG (%)
Aluminium	18,900	0.12	5,576	3,024	504,636	7%
Bitumen	11,022	0.07	46	32	2,204	0%
Carpet	9,381	0.06	1,091	2,695	73,174	1%
Ceramics	891,707	5.89	16,853	13,554	1,159,219	16%
Concrete	9,870,942	65.21	25,664	36,522	2,369,026	32%
Copper	5,237	0.03	786	1,513	52,890	1%
Glass	35,492	0.23	1,012	1,143	70,984	1%
Insulation	42,615	0.28	2,433	2,651	161,935	2%
Paint	18,948	0.13	2,350	3,733	119,375	2%
Plasterboard	231,057	1.53	2,696	2,759	182,535	2%
Plastics	13,847	0.09	1,759	6,134	106,625	1%
Sand & stone	2,541,084	16.79	1,118	4,752	76,233	1%
Steel	947,031	6.26	27,937	41,953	1,988,766	27%
Timber	498,943	3.30	9,525	13,302	593,742	8%
Total	**15,136,206**	**100**	**98,845**	**133,767**	**7,461,344**	**100%**

Municipal carbon emissions in 2018–21 averaged 1.43 million tonnes.

Embodied carbon in buildings in 2021 was approximately 5 times the total municipal emissions.

Our output shows the building stock intensity is highest in the Darwin CBD and its immediate surrounds, as well as in some areas in Berrimah, Muirhead and Nightcliff, (Figure 47). The corresponding intensity of embodied carbon resulting from building construction is concentrated in the same areas (Figure 48).

Improving the circular economy of the urban built environment will be key to Darwin's sustainable future. To achieve this, government policies are needed that enable and encourage reuse, repair and refurbishment of buildings, as well as a focus on the guided procurement of building materials and technologies that are more environmentally friendly and that increase the use of secondary materials.

Resources

- City of Darwin 2030 Climate Emergency Strategy
- City of Darwin 2030 Greening Darwin Strategy
- City of Darwin 2030 Movement Strategy
- Northern Territory Climate Change Response: Towards 2050
- Mousellis and Sons concrete recycling plant (Berrimah)
- NTEX
- Snapshot Climate – Australian Emissions Profiles

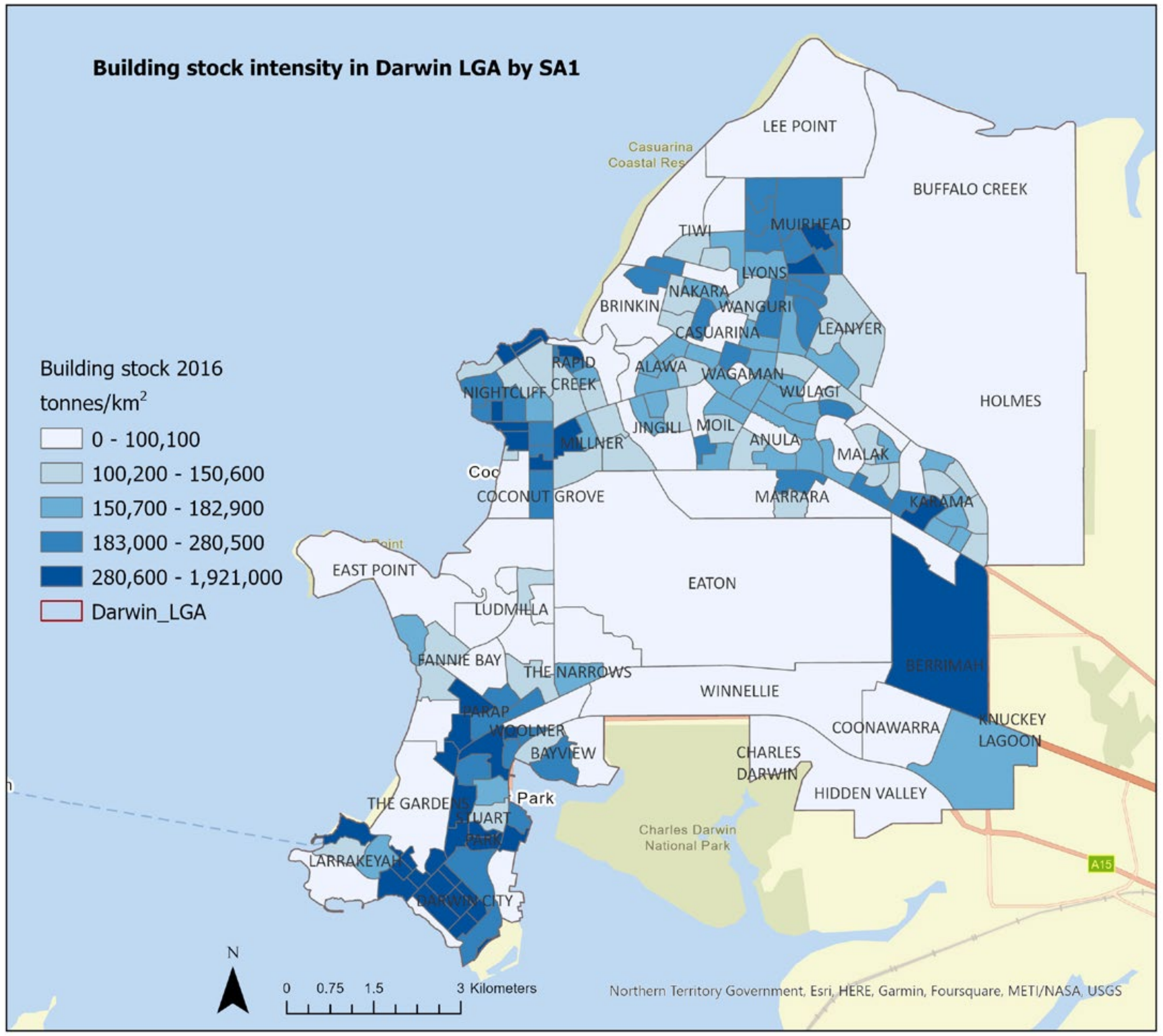


Figure 47. Material use intensity in major types of buildings in Darwin in 2016 by statistical area level 1.

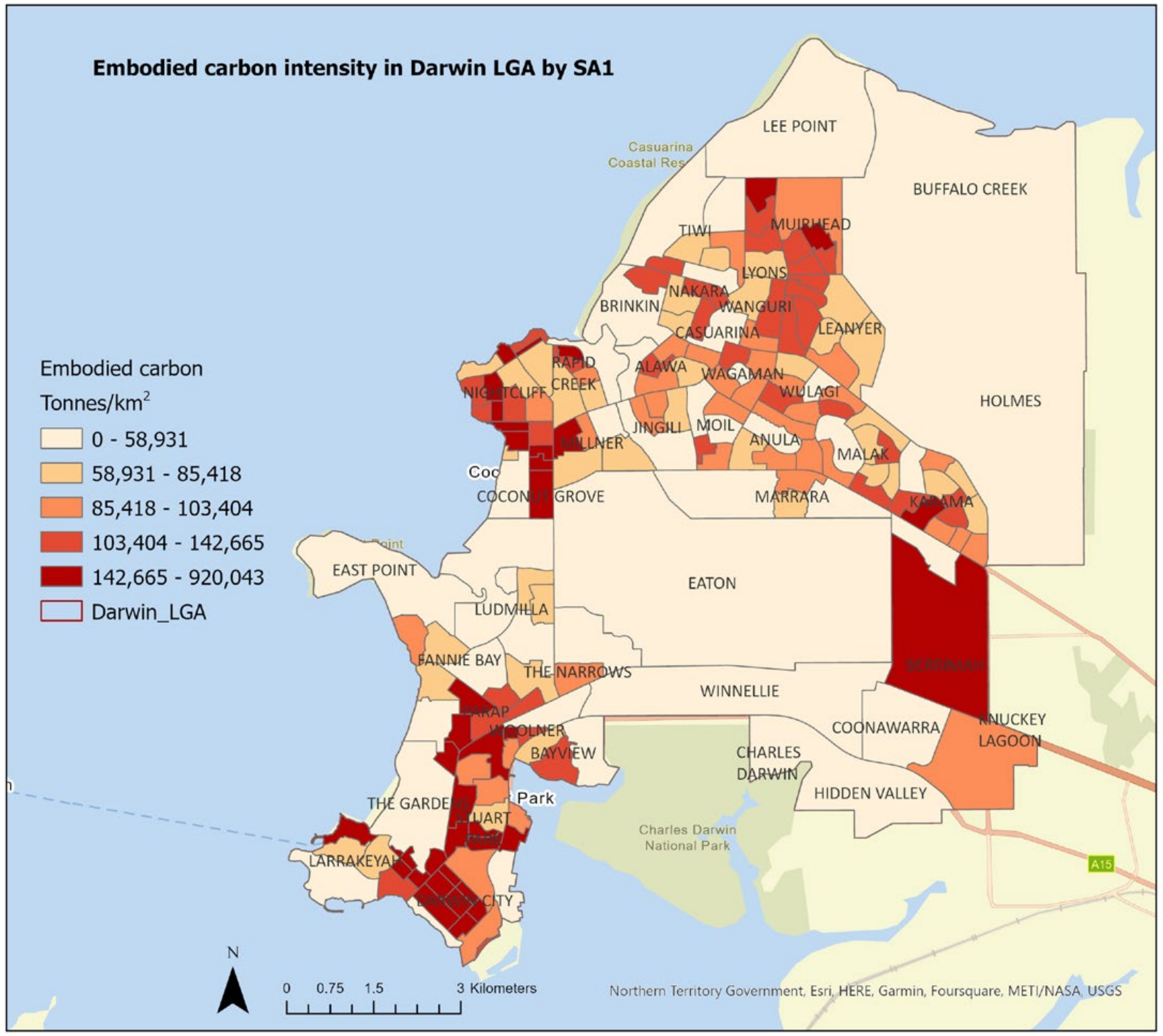


Figure 48. Embodied carbon intensity in major types of buildings in Darwin in 2016 by statistical area level 1.

05 Indoor Liveability

Darwin's hot year-round climate and humid build-up and wet season result in higher energy demand to cool buildings compared to most other Australian cities. A typical NT household consumes about 8,500 MWh of energy each year, almost double that of a typical household in New South Wales;[89] over half of this household energy is used for cooling. The need for cool indoor environments is critical for avoiding human health problems from heat stress (overheating).

Most Darwin households rely upon air-conditioning to maintain thermal comfort during the build-up and wet seasons. However, air-conditioning can be expensive to install and use, creates GHG emissions through electricity use, and emits heat from air-conditioning exhausts – adding heat to outdoor areas. The projected warmer climate will increase pressure on the need for buildings to perform the critical role of providing liveable (i.e. comfortable) and sustainable (i.e. energy-efficient) indoor environments.

Not everyone has the luxury of living in a high-performing and thermally comfortable home. In fact, studies have found that low-income households in Darwin are more likely to live in poorly designed housing, with less financial capacity to ensure thermal comfort.[90] Problems become particularly acute where occupants of low-income households are vulnerable to heat stress and are not able to afford high energy bills from running the air-conditioner. Mechanisms are needed to improve passive design, find retrofit solutions and provide equitable access to energy to prevent heat stress for the vulnerable.

In addition to ensuring that new homes built in Darwin are energy-efficient, there is a role for existing houses and other buildings to generate energy through the installation of solar PV. This would require grid stability to be managed through integrated energy storage (as highlighted in 04 Sustainability: Towards Net-Zero).

Darwin's housing stock

Cyclone Tracy in 1974, and the subsequent introduction of building energy performance standards, have had a significant influence on building design for Darwin. Following the devastation of Cyclone Tracy, when about 70% of houses suffered serious structural failure, there was renewed focus on rebuilding homes to withstand extreme wind events; this led to the increased use of steel frames and a greater use of blocks, concrete and bricks. The gradual introduction of minimum standards for energy efficiency and the adoption of the NatHERS have established a focus on orientating buildings to take advantage of breezes, having wider eaves for shading and using lighter colours. Figure 16 shows that lighter-coloured roofs are prevalent in new suburbs, such Muirhead. The building footprints generated from UrbanMonitor™ show that the new developments of Bayview and Muirhead were designed to be orientated to capture cooling breezes from the north-west (Figure 49).

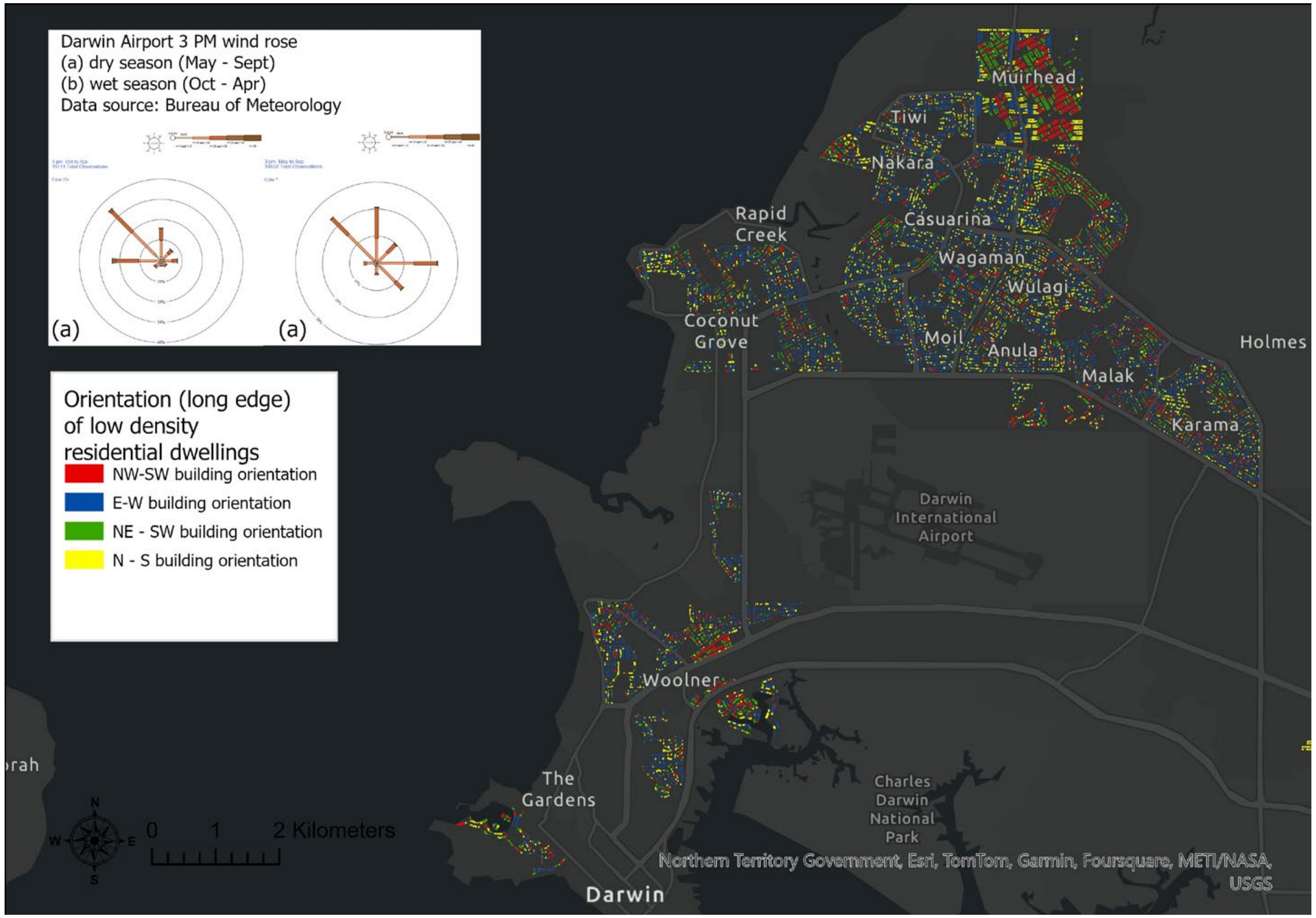
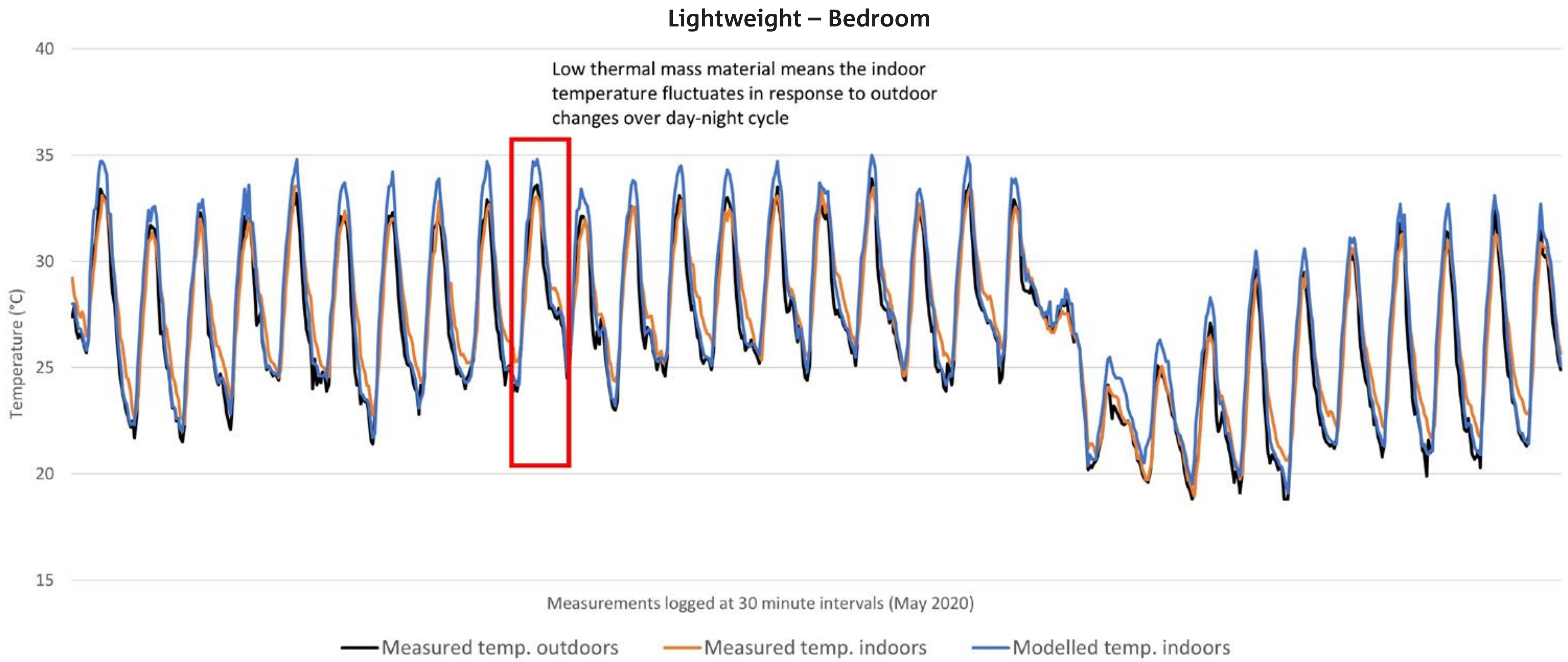


Figure 49. Orientation (long edge) of low-density residential dwellings.

89 Powering the NT | Power and Water Corporation | Have your say (powerwater.com.au)
90 Steinborner et al. (2016) Smart cooling in the tropics report.

Darwin house design has evolved over time. Traditionally, homes were designed to maintain thermal comfort in the tropical climate without air-conditioning. This was reflected in a predominance of lightweight elevated homes with large openable windows for ventilation and large eaves and balconies for shading (Figure 50a). In recent decades, the design of homes has shifted to increased use of high thermal mass materials (e.g. concrete blocks) and less window area, which are designed to meet minimum energy-efficiency standards and rely on air conditioners to maintain thermal comfort (Figure 50b).

Without the use of air conditioners, a lightweight home is likely to mimic the day–night cycle of outdoor conditions, whereas a heavyweight home maintains more consistent internal conditions. The heavyweight well-insulated design can be advantageous for energy-efficient cooling, but can be limited in using passive cooling approaches such as cross ventilation, whereas lightweight design can be efficient in using cool breezes when available.



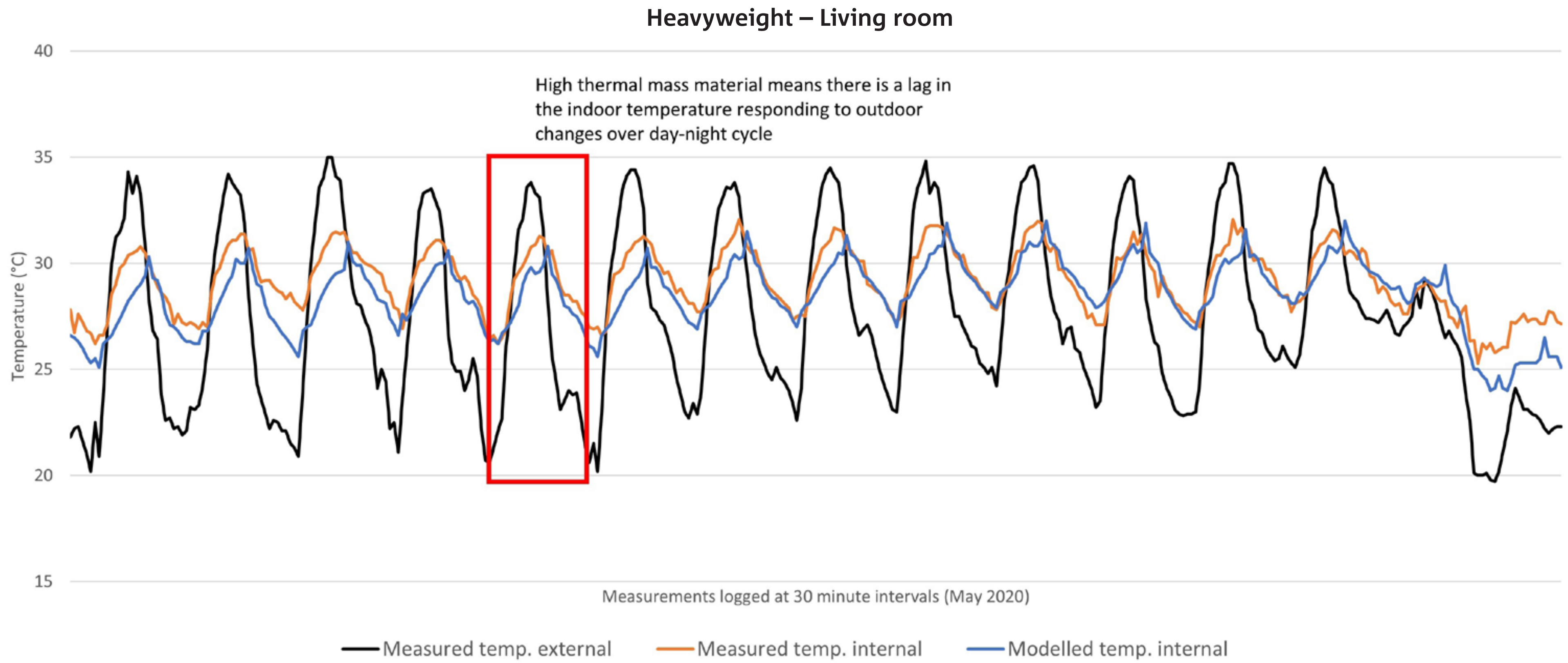


Figure 50. Darwin house design: (a) older design – elevated lightweight, (b) newer design – slab-on-ground heavyweight. Source: Williamson, T. (2023) Empirical validation of house rating software predictions and Darwinian's thermal comfort thresholds, Darwin Home Comfort Rating Forum – March 2023.

Figure 51 shows a map of the age of Darwin housing by suburb based on activation date in the cadastre (noting there is a lag between the date of activation of the parcel of land and its development). This shows that pre-Cyclone Tracy development was concentrated in suburbs close to the CBD (Parap and Stuart Park) and the Nightcliff/Rapid Creek area. The northern suburbs were largely developed in the rebuilding of Darwin following Cyclone Tracy. More recent development has occurred in Lyons and Muirhead, and Berrimah. Figure 7 provides further insight on how the built area in Darwin grew over the period 2011 to 2021.

The Australian Housing Data website has been capturing information on residential home designs since 2016. The Darwin House Comfort Rating project revealed that most new builds have been separate housing with floor areas between 100 and 180 m^2 (average 119 m^2) and air-conditioned areas between 60 and 120 m^2. In Darwin's favour, floor areas are lower than the national average[93] which exceed 200 m^2.

Figure 52a shows the tenure type and percentage of separate dwellings (Class 1) by suburb. It shows that households in suburbs close to the CBD are less likely to be in separate dwellings and are more likely to be renting. In Darwin City, more than 98% of people live in flats or apartments, and three quarters are renting. The northern suburbs are part of Darwin's mortgage belt, with many households owning separate dwellings with a mortgage. In established northern suburbs such as Anula, Jingili, Nakara and Wulagi more than 95% of homes are separate dwellings. More recently developed northern suburbs still have a high percentage of separate dwellings (Lyons 81%, Muirhead 91%), which are mostly occupied by families with children.

Figure 52b shows the percentage of dwellings with surplus bedrooms, based on the ABS's housing suitability variable that compares the available bedrooms with household demographics.[91] It shows that in more recently established suburbs (Bayview, Lyons and Muirhead) more than 80% of dwellings had surplus bedrooms. This reflects the trend for increasing floor area in new developments and has implications for energy demand for cooling. Research has shown that new homes are more energy efficient per metre square of floor area, yet these gains can be wiped out by increasing the floor area of new builds, which means overall home energy demand continues to increase.[92]

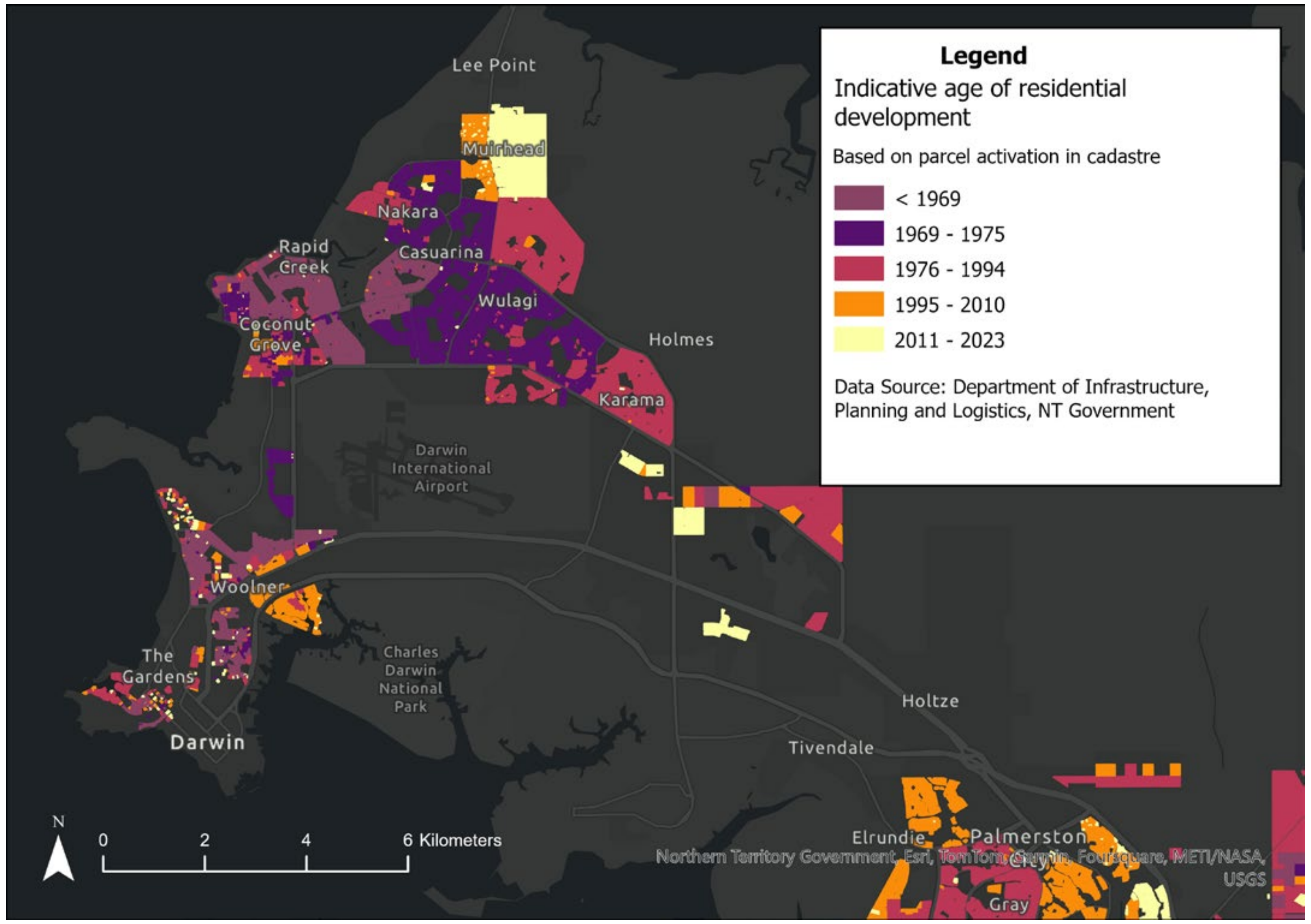


Figure 51. Age of housing development (by cadastre date).

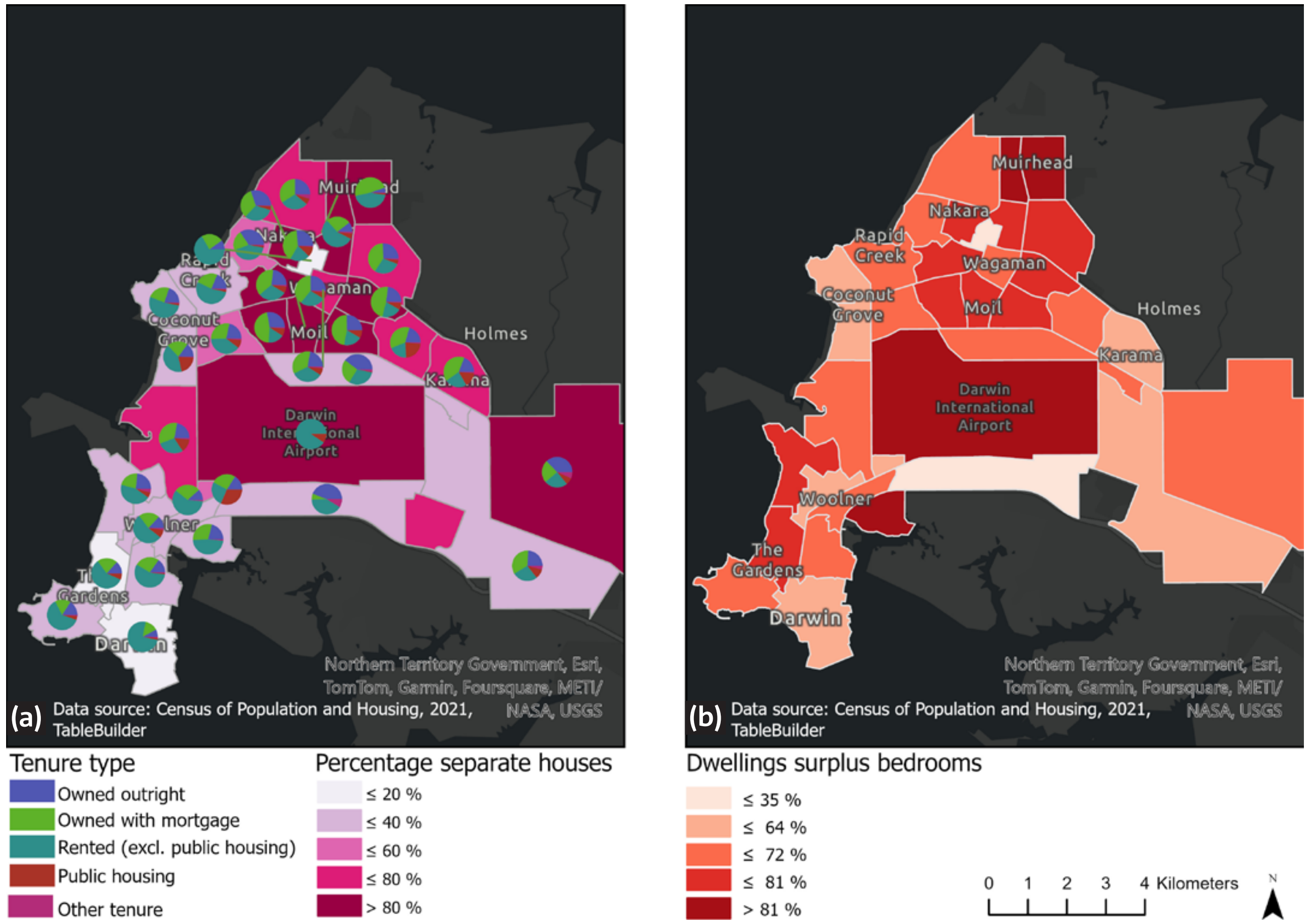


Figure 52. Housing by suburb: (a) tenure type and percentage of separate houses, (b) percentage of dwellings with an extra bedroom. Source: ABS, 2021.

91 https://www.abs.gov.au/census/guide-census-data/census-dictionary/2021/variables-topic/housing/housing-suitability-hosd

92 Wingrove et al. (2023) Increase home energy use: unintended outcomes of energy efficiency focused policy. https://doi.org/10.1080/09613218.2023.2301574

93 Australian houses are world's biggest: CommSec Home Size Trends Report (commbank.com.au)

Thermal performance and energy efficiency

Figure 53 shows the NatHERS energy rating distribution for Class 1 (separate house) and Class 2 (apartment) buildings, and their construction characteristics based on Australian Housing Data. Separate houses have an average 6.6-star rating, whereas apartments achieve higher efficiency ratings. Under current NT minimum energy-efficiency standards for new dwellings, separate houses must achieve at least a 5-star energy rating (this also applies to major renovations of existing houses), and apartments must achieve a minimum 3.5-star energy rating. New builds in all Australian states and territories, except NT and Tasmania, must meet 7-star NatHERS performance.[94]

The Australian Housing Data website provides additional information about housing designs and measures that have been used for new homes in Darwin since 2016:

- External walls are predominately (74%) concrete block.
- Ceiling fans are a critical measure, with the average home having 5–7 fans.
- Very few houses are designed to include wall or ceiling insulation.
- To meet energy-efficiency ratings, windows have become smaller; they are 30–50% smaller than the national average to achieve the same star rating.

Raised houses, although potentially more expensive to build, are not precluded due to energy-efficiency regulations. There are raised house designs that meet 7-star NatHERS rating, demonstrating that block homes on concrete slabs are not the only solution.[95]

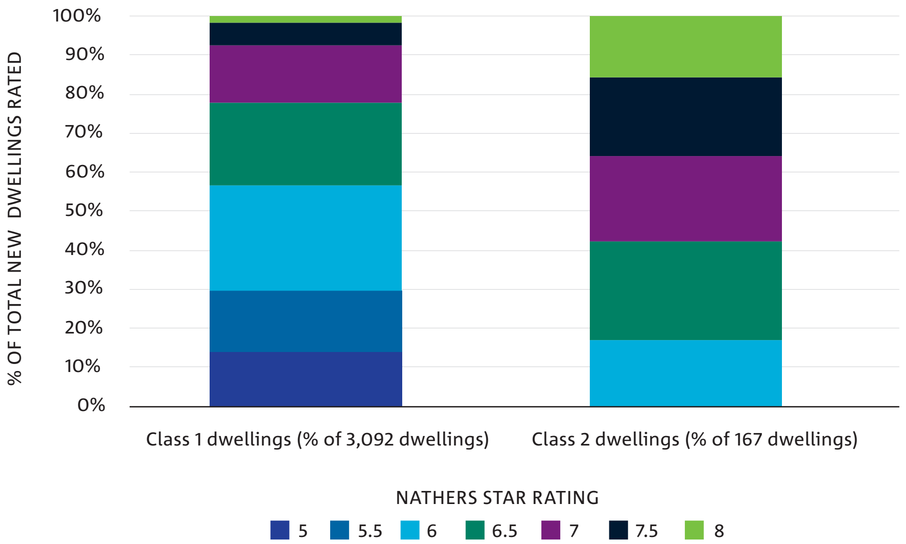


Figure 53. NatHERS energy star rating distribution for Class 1 (separate house) and Class 2 (apartment) buildings in Darwin.

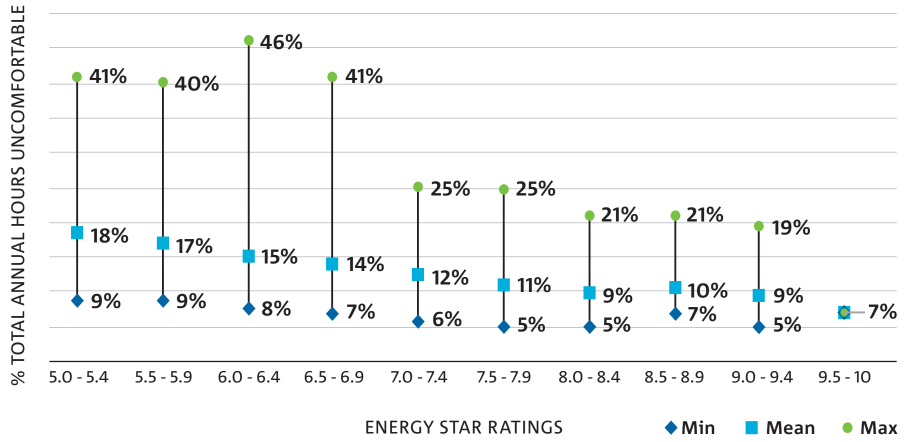


Figure 54. Percentage of time that spaces in the home are uncomfortable (based on the main living area and worst performing bedroom) for 893 separate houses and townhouses in Darwin, showing correlation with NatHERS energy ratings. Source: Miller, W (2023) Darwin Home Comfort Rating System design and analysis, Darwin Home Comfort Rating Forum 30 March 2023.

Overheating and energy-efficiency challenges

Achieving indoor thermal comfort during the day is typically a different challenge than achieving comfort at night, especially in Darwin's hot and humid climate. Getting a good night's sleep is critical to maintaining good health – therefore, houses need to be designed to achieve thermal comfort at night as well as during the day.

In a project led by CSIRO's Building Energy team and the NT Department of Infrastructure, Planning and Logistics, home comfort ratings were built into NatHERS AccuRate software to provide industry with information on how to optimise home designs for comfort. The tool assesses the whole building design but provides specific information on the performance of the main living area and worst performing bedroom. Within this work, comfort thresholds were determined for Darwin residents based on 'in home' experiments led by the University of Adelaide[96] (Table 5). The use of an 'effective temperature' also provided a way to take into account both temperature and humidity; these adaptive comfort thresholds also consider how we naturally adapt to experiencing heat seasonally.

Table 5. Monthly comfort thresholds for living and bedroom zones (effective temperature °C) where 80% or 90% of people remain comfortable.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Living zones	90%	29.59	29.54	29.51	29.50	29.21	28.66	28.44	28.71	29.43	29.86	30.02	29.83
	80%	31.29	31.24	31.21	31.20	30.91	30.36	30.14	30.41	31.13	31.56	31.72	31.53
Bed-rooms	90%	28.49	28.44	28.41	28.40	28.11	27.56	27.34	27.61	28.33	28.76	28.92	28.73
	80%	29.99	29.94	29.91	29.90	29.61	29.06	28.84	29.11	29.83	30.26	30.42	30.23

The project identified that current designs for Class 1 homes in Darwin, with no air-conditioning turned on, have uncomfortable spaces (too hot or humid) for up to 45.9% of the year (Figure 54). At a minimum, uncomfortable spaces were felt for between 5% and 8.8% of the year across all energy ratings, but a shift to 7-star energy ratings for new dwellings (as required in other parts of Australia) would greatly decrease the range of thermal performance towards more comfortable housing.

Queensland University of Technology led the development of the rating scheme based on CSIRO NatHERS data; the full report is available online. A future Darwin Living Lab project will seek to roll out the Home Comfort Rating tool through collaboration with NatHERS industry assessors.

If you are planning to build a new home, ask your NatHERS assessor to obtain this additional information on thermal performance, and work with them to improve comfort outcomes.

Why should you care about thermal comfort ratings?

- Not everyone can afford to rely on air-conditioning.
- Homes overheating can affect people's health, quality of life and willingness to live and work in the Territory.
- Homes should be as comfortable as possible during power outages.
- Energy use from air-conditioning is a major contributor to GHG emissions.

94 NEWS: NT refuses to adopt new 7 Star Energy Efficiency standards for homes » Healthabitat
95 Ambrose Darwin Living Lab webinar: Energy efficiency and renewables in moving towards a cooler Darwin – Darwin Living Lab (csiro.au)
96 Videos of keynote presentations and panels – Darwin Living Lab Symposium 2022 – Darwin Living Lab (csiro.au)

The impact of outdoor temperatures on indoors

Average maximum and minimum temperatures in Darwin have been increasing (Figure 9). The average number of days per year above 35°C has increased from around 10 days for the period 1961–1990 to 20 days for the period 2008–2017.[97] Higher temperatures increase energy demand for cooling. Data modelling suggests that increasing temperatures and heat island effects in the City of Darwin could double or triple energy demand and increase heat mortality.[98]

In 2021–22, the total annual electricity consumption from the Darwin-Katherine power system was 5.5% higher than the previous year.[99] This can be attributed in part to higher temperatures in the Darwin subregion in 2021–22, which recorded the highest number of days in recent history (275 days) where the maximum daily temperature exceeded 32°C – 78 more days than the previous year (197 days).

As discussed in 01 Urban Heat Island, parts of Darwin will have different climatic conditions depending on local factors, such as proximity to water bodies, greening and trees, and heat-absorbing materials. It will take a coordinated effort for all stakeholders to contribute to cooling outdoor environments, but there are actions that home and business owners can take outdoors that can assist to provide a more liveable indoor environment.[100]

- Planting a shade tree to the east, west or north of buildings can reduce electricity usage by a few percent.[101]
- Installing engineered shade or facades have been reported to decrease cooling energy demand up to 40%.[102]
- Establishing green roofs and green walls can assist in shading and insulating the indoors.
- Choosing lighter colours for roofs and exteriors can reflect solar energy.

Hot air from HVAC exhausts (as a result of cooling the indoors) can also impact outdoor temperature, with an effect that is most noticeable at night.[103] Recent studies along Smith Street in Darwin showed that 87–95% of anthropogenic (human-generated) daytime heat was from air conditioners in buildings and 4–13% was from automotive engines.[104] Best practice is to place compressors in a shaded spot, and ideally where hot exhaust air can be released into spaces (or at a height) where heat can be taken away by prevailing wind.

97 Hanna and Ogge (2018) Cooked with gas – extreme heat in Darwin
98 https://intouchpublichealth.net.au/urban-heat-islands-darwin-as-a-case-study-in-climate-change-adaptation/
99 2022 NT Electricity Outlook Report
100 Law et al. (2021) Design for liveability in tropical Australia. Leading from the North: Rethinking Northern Australia Development. https://doi.org/10.22459/LN.2021.20
101 Pandit and Laband (2010) Energy savings from tree shade. https://doi.org/10.1016/j.ecolecon.2010.01.009
102 Sarihi et al. (2021) A critical review of façade retrofit measures for minimising heating and cooling demand in existing buildings. https://doi.org/10.1016/j.scs.2020.102525
103 Anthropogenic heating of the urban environment due to air conditioning – Salamanca – 2014 – Journal of Geophysical Research: Atmospheres – Wiley Online Library
104 Rajapaksha et al. (2022) An estimation of the anthropogenic heat emissions in Darwin city using urban microclimate simulations. https://doi.org/10.3390/su14095218

Case study – Monitoring of naturally ventilated short-term accommodation

Crear Road is a service that provides short-term accommodation for Aboriginal families travelling from remote communities to Darwin to access medical and other essential services. Two buildings that rely on natural ventilation and fans were monitored using heat stress sensors to assess their indoor climates. Figure 55 shows images of the two building designs – the Harmony design and the Village design. Figure 56 presents selected data showing that both buildings are likely to be outside acceptable thermal comfort thresholds during the hottest part of the year (noting that the monitoring period occurred during a hotter-than-average period in December 2023, where the average daily maximum was 1.4°C hotter than the long-term average for December).

The Harmony design provided a slightly cooler indoor environment than the Village design, probably because of better design features such as orientation to prevailing breezes, windows that allow for cross ventilation and air movement, and shading of windows.

Design improvements for this type of accommodation are necessary to avoid overheating, particularly given the increasing occurrence of heat extremes and the need to care for people with heat vulnerabilities.

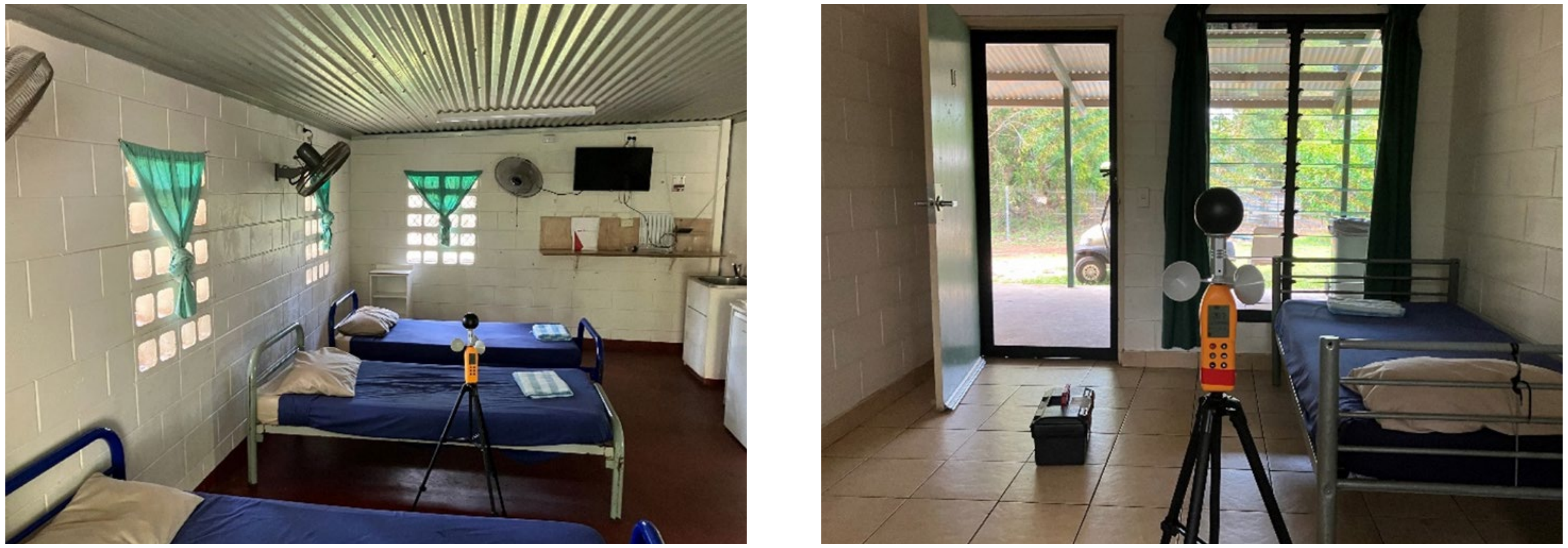


Figure 55. Two accommodation designs monitored in December 2023. Left: 'Village design', cement block walls of a light colour, uninsulated and unventilated roof with reflective foil (sarking), minimal shading by eaves with no eaves on the west and east orientations, ventilation provided by air bricks with little potential for cooling from cross breezes, and 450 mm mechanical wall-mounted fans. Right: 'Harmony design', cement block walls of a light colour, uninsulated and unventilated roof with reflective foil (sarking), rooms orientated to the north-west to capture prevailing breezes, large eaves providing shade, ventilation through louvre windows with 90% opening to the breeze, and ceiling fans.

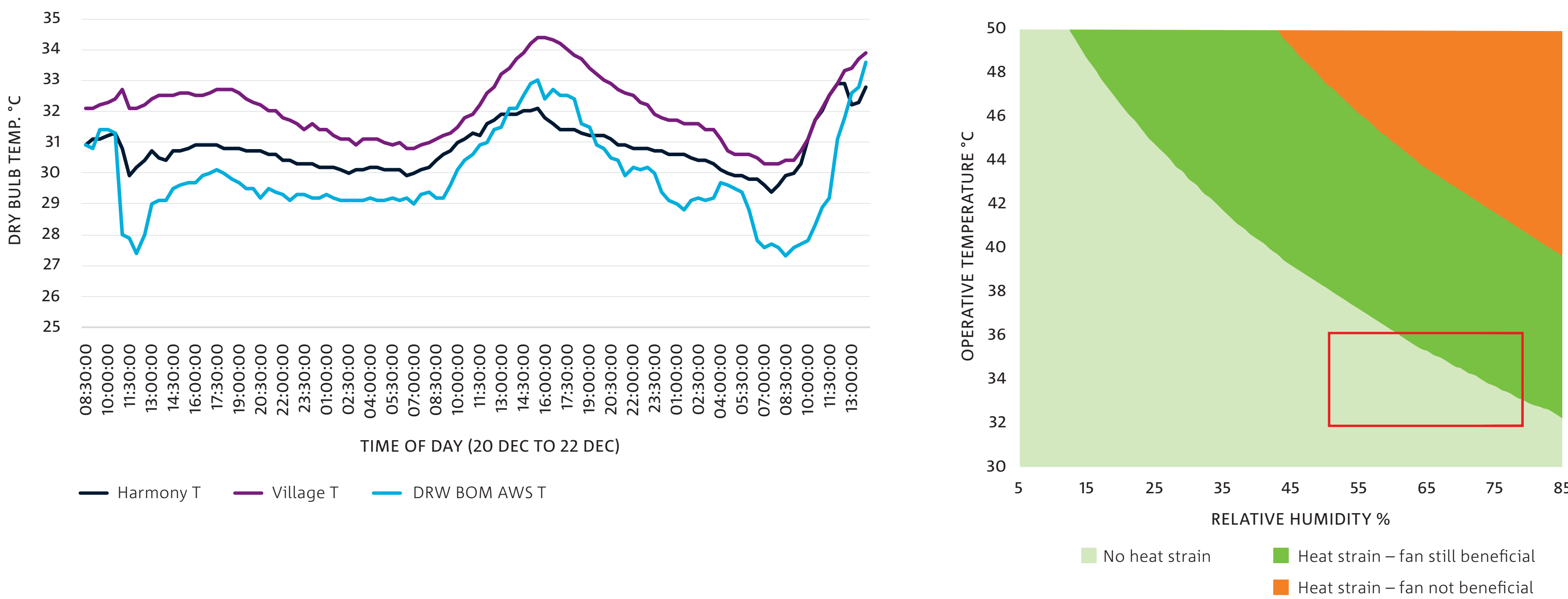


Figure 56. Left: Representative dry bulb temperature data in the living space of Village and Harmony designs in December 2023 (Bureau of Meteorology Darwin airport data provided as a reference). Right: Indicates the potential for fans to provide cooling benefit for the temperature and relative humidity conditions observed (red box) assuming someone at rest and wearing light clothing. Light green – the use of fans provides more cooling to the human body than still air. In the dark green region, the use of fans is still beneficial, but people are most likely suffering from heat strain (https://comfort.cbe.berkeley.edu/).

How people use buildings

Many decisions made on how to cool the home are related to the comfort of the individual or the collective vote of an acceptable 'setpoint' for temperature and humidity. Residents can change their thermal comfort either by changing their individual behaviour (e.g. changing clothes or activities, taking a shower or drinking water) or their environment (e.g. opening a window or changing air-conditioner setpoint).[105] Many homes in Darwin use a combination of air-conditioning and natural ventilation to maintain thermal comfort. In these cases, the homeowners play an active role in achieving indoor comfort.

In commercial and office buildings in Darwin, which usually have automated air-conditioning setpoints, some people would like to see a shift away from wearing formal workwear (e.g. suits), and for clothes such as shorts and sarongs to be more acceptable as business attire.[106] This would not only be more thermally comfortable, but it may reduce demand, cost and emissions associated with air-conditioning large buildings. It is estimated that for every 1°C decrease in setpoint temperature for cooling, air conditioners use an additional 5–10% of energy.[107] The 'thermal mavericks' of Darwin are more comfortable with higher setpoints, so should the average home and workplace consider using higher setpoints to cut down on electricity use and its associated costs and GHG emissions? How would visitors to Darwin cope with this?

Resources

- Territory Renewable Energy (nt.gov.au)
- Power and Water Corporation (Saving energy)
- Tropical and sub-tropical living | energy.gov.au
- Heating and cooling | Your Home
- City of Darwin 2030 Climate Emergency Strategy

105 Safarova et al. (2022) Thermal comfort in tropical savanna climate the case of home occupants in Darwin, Australia. https://doi.org/10.1016/j.enbuild.2022.112074

106 Darwin Living Lab Symposium 2019

107 Heating and cooling | YourHome

Summary of key questions for Focus on Darwin

01 Urban Heat Island – there are a number of initiatives underway to reduce temperature and improve the liveability in Darwin – what works and what doesn't?

The Darwin CBD is 2–3°C hotter than many rural areas due to urban materials such as asphalt, concrete and bricks which reach up to mid-60°C, absorbing and holding heat. Hotter parts of the city have paving and bitumen, rooftops, bare ground with fewer trees and unirrigated dry grass. Cooler areas have water, trees, irrigated grass and proximity to coast.

Critical measures can be taken to reduce the urban heat island in Darwin:

- **Shade:** shaded surfaces have temperatures up to 21.2°C cooler than sun-exposed surfaces. Trees are particularly good at creating shade, and they also cool via evapotranspiration (drawing up water from deep in the soil long into the dry season). On the flipside, trees take time to grow and they cannot be planted everywhere. Installing engineered shade can be a good option.
- **Water in the landscape:** water underpins evaporative cooling at the city scale. Water misting is extremely effective at outdoor cooling when used appropriately – and there is the opportunity to increase its use in Darwin.
- **Allowing for breeze:** breeze has a cooling effect on humans, and removes heat from the urban landscape. Urban and building design should allow for Darwin's prevailing north-west breezes to flow through the urban landscape.
- **Lighter-coloured surfaces:** light colours reflect solar heat, and choosing light-coloured (cool) roofs can help cool both the outdoors and inside buildings. Conversely, light-coloured pavements while having an overall cooling effect can make pedestrians feel hotter when the sun is directly overhead. Heat-reflective coatings on pavements go some way to reduce the surface temperature.

02 Healthy outdoor environments are an important part of liveability – how do the people of Darwin interact with the outdoor environment and how does that outdoor environment return benefit?

Darwin's character and liveability are largely derived from natural places and green spaces, which are 'part of the atmosphere'. The importance of natural environments is a shared value across demographics (i.e. traditional owners and the general population). Natural systems are however stressed by urbanisation and a warming climate.

Among a range of factors that reduce liveability in Darwin, the key factors were humidity, heat/temperature, invasive plants, pest animals and smoke from fires. Factors that affect liveability to a lesser extent are dangerous species and shopping options.

The uptake of outdoor activities could be increased by improving access to natural places and green spaces. This includes access to Country, equitable access to cool places for vulnerable people, increased public transport to natural places, and the creation or reopening of natural, safe places to swim and keep cool. Vibrant and active outdoor environments can be made more comfortable through the provision of shade, primarily by planting trees that are climate ready and resilient to cyclones. There are opportunities to better manage weeds and control savanna burning to improve Darwin's air quality.

03 Water is a key resource (for cooling) – how much water is needed for a cool and liveable Darwin, and how much pressure does that put on a sustainable and resilient water supply for Darwin?

Water is fundamental to creating a cooler and more liveable Darwin. Land surface temperatures show that cooler parts of the city tend to be in the proximity of the coast, near a water body, or areas where water has sustained healthy tree and vegetation growth.

Darwin's residential water use has declined over the past decade, yet per capita usage remains twice the average of other Australian capital cities and it is still high when compared to other centres in northern Australia. Over half of all water use in Darwin is to irrigate gardens, and while this helps Darwin to stay cool, it places pressure on the sustainability and resilience of Darwin's water supply.

Irrigation patterns have been explored at lot scale across Darwin's suburbs. Marrara has the highest area of irrigated grass per residential lot due to its large lot sizes and proximity to the golf course estate. Newer northern suburbs (Lyons and Muirhead) have the highest building to lot ratios, yet – along with Marrara – have the highest proportion of irrigated grass on unbuilt areas of the lots (~10%). Older suburbs such as Nightcliff and Rapid Creek, despite being on larger than average lots, had a relatively low average area of irrigated ground cover on residential lots, which in part is explained by high tree canopy cover in these suburbs. Newer areas with fewer established trees, have greater amounts of irrigated ground cover (and likely higher water consumption), whereas areas with established trees have lower amounts of lawn and lower water requirements.

The use of shade trees and irrigated green space reduces temperatures in urban landscaped areas through shading and evapotranspiration cooling, which improves thermal comfort and can reduce building energy demand. Trees should be prioritised over irrigated grass to cool Darwin, as they provide additional shading benefit and require lower amounts of water (as they can draw water up from deep soil longer into the dry season compared to grasses).

Water efficiencies can be made through an increase in tree shade canopy, smart irrigation systems, and metering of water to enable early leak detection. Other advances may include water-sensitive urban design to assist passive irrigation of trees, and water recycling to improve Darwin Harbour water quality and provide a climate-independent water source.

04 Sustainability: towards net-zero – what is the situation, and how can Darwin, with all its challenges, adapt to a net-zero future?

Darwin's embodied carbon in the built environment has been estimated at 7.5 million tonnes (CO_2 equivalent), about five times Darwin's annual GHG emissions, which yearly averages from 2018 to 2021 are estimated at 1.43 million tonnes (CO_2 equivalent) per year.

Major contributions to Darwin's GHG emissions are from the electricity grid, gas, transport and, to a lesser extent, waste.

Renewable energy contributions to the electricity grid are currently less than 1% despite about one third of dwellings having solar PV. Solar PV, however, plays an important role to provide liveable and sustainable indoor environments. When the sun shines and it is hot, the renewable energy generated can be used directly to run air conditioners. Peak demand no longer occurs mid-afternoon, but has shifted into the evening due to increased levels of solar generation during the middle of the day.

Buildings can play a significant role in stabilising the electricity grid and empowering the uptake of electric modes of transport. New homes and buildings can be designed to integrate solar and EV batteries. For larger commercial buildings, there are non-battery options to balance electricity loads and achieve efficiencies; for example, the use of thermal storage (i.e. chilled water) can deliver cooling at reduced cost and increase flexibility in grid demand.

There is almost 10 million tonnes (10 Mt) of concrete within the built environment in Darwin, followed by sand and stone (2.54 Mt), steel (0.95 Mt) and ceramics (0.89 Mt). After the development of the newer suburbs of Berrimah, Lee Point and Muirhead, greater effort will be placed on renewal of established suburbs and population densification. Access to materials from demolition may create the stimulus for increased local recycling and repurposing of materials towards a circular and lower emissions economy.

Road-based transport emissions can be reduced through the increased uptake of electric, active and public modes of transport. Active transport and public transport reduce private car use, reduce road infrastructure (e.g. hot asphalt area) and lower GHG emissions. EVs have lower GHG emissions compared to combustion engine vehicles, and although SUVs may offer greater freedom to explore Darwin's natural surrounds, the high number of short commutes and day-to-day trips are suited to EVs. Emerging forms of electric micromobility such as gophers, e-scooters and e-bikes are emerging as an option to reduce heat stress for short trips.

Due to the large public sector workforce in Darwin, government-agency emission reductions are likely to significantly reduce Darwin's emission footprint.

05 Indoor liveability – how can improvements in tropical design lead to more liveable and sustainable indoor environments?

Achieving indoor thermal comfort is critical in Darwin's hot and humid climate. Buildings need to be designed to perform well during the day, and also at night – getting a good night's sleep is essential for good health.

The modern design of Darwin homes has shifted away from raised houses and increasingly towards high thermal mass materials (e.g. concrete blocks) to help meet minimum energy-efficiency (sustainability) standards, and air conditioners are used to avoid overheating and maintain thermal comfort.

Current minimum energy-efficiency standards in the NT (5-star for separate houses and 3.5-star for apartments) are below that of most other states and territories (7-star). However, many Darwin homes already achieve a 7-star rating. Since 2016, building designs for separate houses in Darwin have achieved an average 6.6-star rating, and apartments achieve higher efficiency ratings. Many raised house designs are also able to achieve a 7-star rating, demonstrating that block homes on concrete slabs are not the only option.

Despite meeting energy-efficiency standards, some houses in Darwin have spaces that are uncomfortable (too hot or humid) for up to 45.9% of the year without air-conditioning. Recent efforts have added a new module to national energy star rating assessments to provide users with information on thermal comfort, and not just energy efficiency.

Key housing design elements used for new homes in Darwin since 2016:

- External walls are predominately (74%) concrete block.
- Ceiling fans are a critical measure, with the average home having 5–7 fans.
- Very few houses are designed to include wall or ceiling insulation.
- To meet energy-efficiency ratings, windows have become smaller; they are 30–50% smaller than the national average to achieve the same star rating.

In more recently established suburbs (i.e. Bayview, Lyons and Muirhead) more than 80% of dwellings have surplus bedrooms. This reflects the trend for increasing floor area in new developments and has implications for energy demand for cooling. New homes are required to be more energy efficient per metre square of floor area, yet these gains can be wiped out by increasing the floor area of new builds, which means overall home energy demand continues to increase.

Improved energy efficiency across all building types can be achieved by using light-coloured (cool) roofs. Shading, to block solar radiation, can be achieved using facades, trees and green walls. In newer suburbs such as Muirhead the streets and homes are designed to allow the prevailing north-west breezes to flow through the urban landscape, removing heat and providing personal cooling.

There are many opportunities to create a cooler and more liveable Darwin for users of outdoor public spaces, such as designing buildings to include balconies and awnings that provide shade for public footpaths and other spaces.

Both energy efficiency and indoor thermal comfort can be greatly improved through the adoption of digital building technologies that increase the contribution of solar PV and decrease costs through effective control temperature setpoints and electromechanical systems. Personal agency can also play a significant role in staying cool, like changing into cooler clothing.

Summary of important principles for creating a liveable, sustainable and resilient Darwin

- Darwin's outdoor spaces are highly valued by the community and are a significant part of the city's atmosphere and liveability.
- Comfortable outdoor spaces are improved by shade and trees, and the opportunity for breezes to flow within lots, streets and parks.
- Keeping water in the landscape provides cooling, and robust ways to do this are needed (e.g. to avoid biting insects).
- Shade trees and irrigated green space reduce temperatures in urban landscaped areas. Planting shade trees with resilience to dry soil conditions and cyclones is ideal.
- Building design should focus on energy efficiency and incorporate measures such as light-coloured (cool) roofs, facades, green walls, awnings and balconies.
- Buildings can play a significant role in electricity grid stabilisation and empower electrified mobility through storage and renewable energy generation.
- Active transport and public transport reduce private car use, reduce road infrastructure (e.g. hot asphalt area) and lower GHG emissions.
- Personal choices are critical for a liveable and sustainable Darwin, including individual and community responses for: staying cool, using indoor and outdoor spaces, selecting modes of transport, and purchasing and disposing of goods.

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research.csiro.au/darwinlivinglab

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