Too Hot to Play:

Quantifying the Impacts of Urban Climate Change on Playground Activity

Version 2 | Date: 09/12/2025

Project team

Riccardo Paolini[1], Sebastian Pfautsch[2], Agnieszka Wujeska-Klause[2], Mahya Parchami[1], Negin Nazarian[1,3], Melissa Hart[3], Judi Walters[2], Prabha Shrestha[2], Liz King[4], Nikki Woolley[5]

[1] School of Built Environment, Faculty of Arts, Design and Architecture, University of New South Wales
[2] Urban Transformations Research Centre, Western Sydney University
[3] ARC Centre of Excellence for Weather of the 21st Century, UNSW
[4] Cancer Council NSW, Skin Cancer Prevention Unit
[5] Cancer Institute NSW, Cancer Screening & Prevention Division

Project contacts: r.paolini@unsw.edu.au, s.pfautsch@westernsydney.edu.au
https://www.unsw.to/too-hot-to-play

Project Partners

University of New South Wales, Western Sydney University, Cancer Institute NSW, Cancer Council NSW

Funding

UNSW/WSU Alliances/Project Mezze Seed Funding – Liveable Communities. UNSW Research Infrastructure Grants supported the procurement of part of the equipment for the High Performance Architecture Lab (2017, 2020, and 2023).

Human Ethics Approval

The project was granted human ethics approval for the use of people-counting devices, which collect anonymous counts of visitation. The human ethics approval number is: iRECS4758. https://research.unsw.edu.au/recs

Acknowledgements

We gratefully acknowledge the support of the City of Parramatta Council, specifically Parks and Open Space Planning, for identifying and providing access to the playgrounds monitored in this project.

Acknowledgement of Country

We pay our respects to the Dharug people, the traditional custodians of the land on which this work has taken place, and to the Bidjigal, Gadigal, Dharawal, and Wiradjuri peoples, whose lands the institutions contributing to this research operate on. This Country has always been a place of teaching, learning and knowledge sharing, and that continues today. We honour the enduring connection of Aboriginal and Torres Strait Islander peoples to this land, culture and community. We recognise the ongoing presence and contributions of Aboriginal and Torres Strait Islander peoples and commit to listening, learning and walking together.

Cover image: Drone-captured view of WR Musto (S. Pfautsch, 2024).

Glossary

- **Albedo** - the fraction of solar radiation (sunlight) that a surface reflects, measured on a scale from 0 (a black body that absorbs all incident radiation) to 1 (a body that reflects all incident radiation)
- **BoM** (Bureau of Meteorology) – Agency of the Australian Government responsible for providing weather services to Australia and surrounding areas
- **NSW DCCEEW** (NSW Department of Climate Change, Energy, the Environment and Water) – Department of the New South Wales Government, responsible for climate change and energy action, water management, environment and heritage conservation and protection.
- **RH** (relative humidity, %) - the amount of water vapour present in the air expressed as a percentage of the amount needed for saturation at the same temperature.
- **SRI (Solar Reflectance Index)** – A number between 0 and 100 that describes how hot a horizontal surface is hot under the sun due to its solar reflectance and emissivity, with 0 being the SRI of a black roof with solar reflectance equal to 0.05 and emissivity equal to 0.90, and 100 being the SRI of a white roof with solar reflectance equal to 0.80 and emissivity equal to 0.90.
- **T_{max}** – the absolute maximum air temperature, typically recorded in the afternoon (°C)
- **T_{mean}** – average summer air temperature (°C)
- **UTCI** (Universal Thermal Climate Index) – a thermophysiological index, or a feels-like temperature, that takes into consideration the effect of solar and thermal radiation, as well as humidity and wind speed on human thermal comfort. More information is available online at https://utci.org.

Note: This project report has not been peer reviewed. Submission of an academic paper to a scientific journal and peer review will follow. The preprint of the manuscript will be made available on the project webpage. The accepted manuscript will be made publicly available after the embargo period, as per agreements with the publisher.

Table of Contents

Executive Summary

Playgrounds are an important part of urban infrastructure to enable children's outdoor play and foster social interaction. However, urban overheating reduces the liveability of outdoor spaces, including playgrounds. It can become "too hot to play". Furthermore, insufficient or inadequate shading increases the risk of unnecessary overexposure to ultraviolet radiation and thus, the risk of skin cancer. Our research project investigates the optimal design for playgrounds that protect the community from heat and UV radiation. Therefore, we investigate three research questions:

- How do quantity and quality of shade and the overall thermal environment affect playground use?
- Are there environmental thresholds for the summertime visitation of playgrounds?
- Which design solutions can prolong playground use under a warming climate?

With support from City of Parramatta Council [Parks and Open Space Planning], we initially identified three playgrounds in Parramatta's Local Government Area: Binalong Park (good artificial shade), Doyle Ground (mixed artificial and natural shade) and WR Musto (no shade).

WR Musto Playground is a local-level playground in Parramatta City Council's playground network. It was scheduled for replacement, as the current equipment is over 20 years old. The playground, in its site context, has been designed with climate-responsive principles, considering the data and recommendations provided in the preliminary report. These include the provision of both natural and built shade, light-coloured surfaces, and a mix of available play areas. Parramatta City Council will consider the performance of newly designed playgrounds and further upgrades following these principles and evidence-based design recommendations resulting from this project, to deliver playgrounds that remain inviting, safe and resilient year-round.

Due to the retrofit plans for WR Musto, we included a fourth playground, i.e., North Rocks Park (limited natural shade). In March 2024, we installed on-site temperature and humidity sensors, as well as people counters that anonymously track the number of people accessing and using the playgrounds (sensors at North Rocks were installed in October 2024). Further, we organised field campaigns on hot summer days with scientific-grade environmental sensors to measure surface temperatures, UV exposure, and "feels like" temperatures.

Key Findings:

- *Thermal Risk:* Surface temperatures on common playground materials frequently exceeded 70 °C, with some reaching over 85 °C, posing serious burn risks. Dark soft-fall surfaces at Binalong Park and North Rocks (both with solar reflectance of only 6%) can reach 85 °C during measurement days, or 45 °C and 54 °C above the air temperature (Figure E1). The only cool surface at playgrounds is natural grass, with a surface temperature close to air temperature (approximately +5 °C above ambient, or between 35 °C and 40 °C during hot days). Air temperatures at playgrounds were consistently higher than nearby weather stations, confirming the presence of urban heat island effects. On a hot day, the playground sites are on average 1-1.3 °C warmer than the closest Bureau of Meteorology weather stations, which provide semi-hourly data at Olympic Park and Horsley Park, with some differences across sites. Further, all playgrounds stay warmer for longer than any Bureau of Meteorology station.
- *UV Exposure:* The UV Index levels regularly reached "very high" to "extreme" categories, even under partial shade during the central hours of the day. Artificial and natural shading reduced UV exposure but did not eliminate the need for personal sun protection.
- *Playground Use:* Visitation and activity declined sharply above 30 °C. Shaded equipment supported higher and more sustained use, especially swings. Playgrounds with better shade coverage showed broader and more intense usage patterns. Visitation to Binalong Park and Doyle Ground playgrounds is concentrated in the 18-32 °C temperature range, while it declines more rapidly after 30 °C at North Rocks.
- *Material Performance:* Low-albedo materials, including dark rubber surfacing, contributed significantly to overheating (+40-45 °C above ambient air). Grass and light-coloured concrete

performed better in mitigating surface temperatures, as irrigated grass reached surface temperatures at most 5 °C above ambient, while concrete or materials with high thermal mass, such as rocks, were at 10-15 °C above ambient.

- *Thermal Comfort:* The Universal Thermal Climate Index (UTCI) revealed that even shaded areas often exceeded thresholds for strong heat stress, with unshaded areas reaching extreme heat stress levels. The UTCI, or 'feels-like' temperature, exceeded 42 °C in the sun and 36 °C in the shade, when the air temperature was 32 °C at Doyle Ground, for instance.

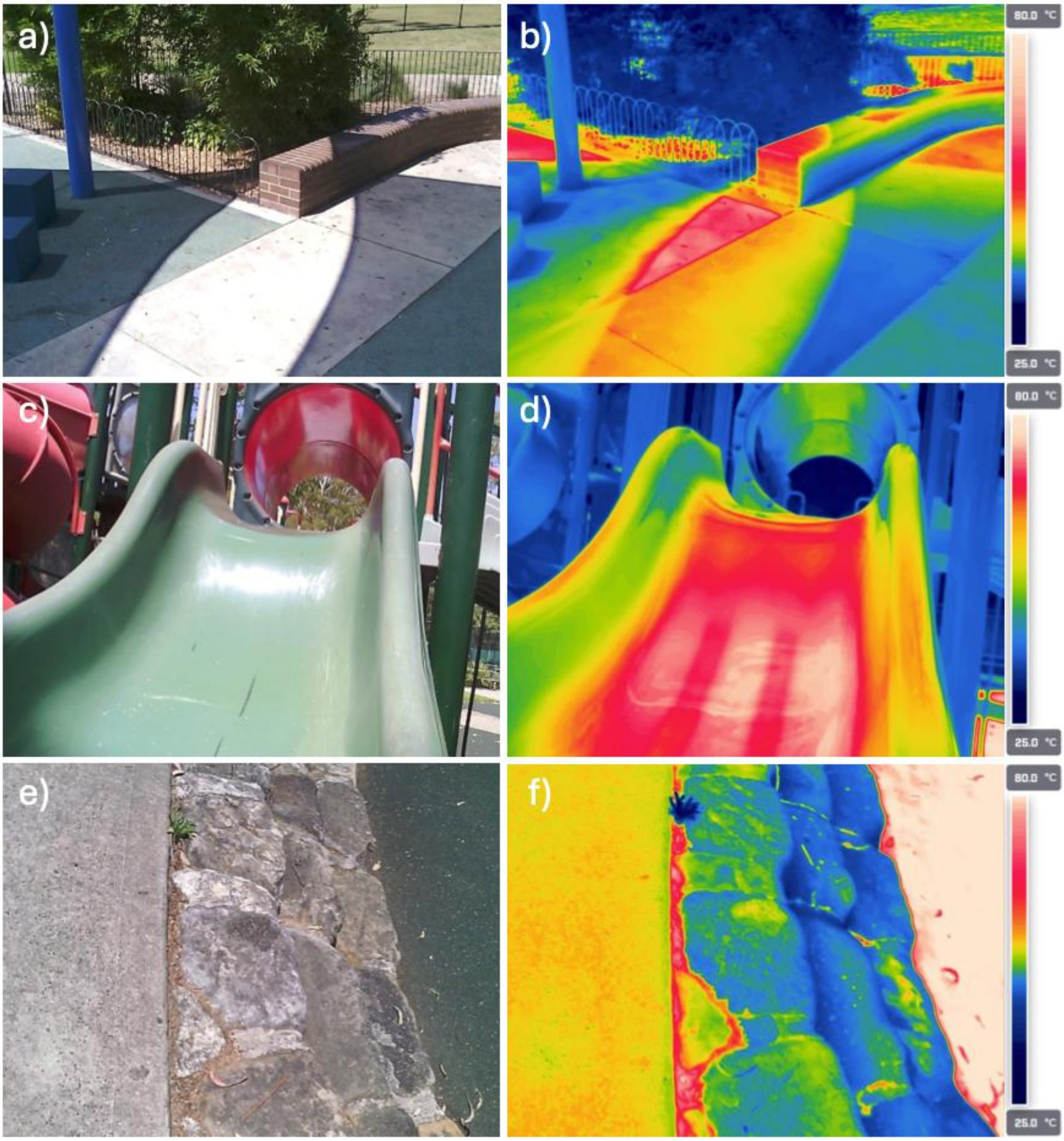


Figure E1. Surface temperature at the investigated playgrounds. Images on the left side depict the normal views and on the right side the infrared view, visualising surface temperature as colour. All images are calibrated to a temperature range of 25-80 °C (see scale bar on far right), with an emissivity of 0.95. Panels a,b: Shaded and unshaded soft-fall and concrete surfaces, bricks and vegetation at Doyle Ground; image taken at 2 pm, 16 December 2024. Panels c,d: Unshaded plastic slide at North Rocks; image taken at 12:08 pm on 7 February 2025. Panels e,f: Unshaded concrete, rock and dark rubber soft-fall surfaces at North Rocks; image taken at 1:03 pm on 7 February 2025.

Implications:

The study underscores the urgent need for climate-responsive playground design. Enhancing shade provision, selecting thermally appropriate materials, and integrating environmental monitoring can markedly improve safety, comfort, and access to outdoor play. These findings provide actionable insights for local governments, urban designers, and community stakeholders aiming to future-proof public play spaces.

Design Recommendations

Materials

- The selection of materials should also be based on their optical and thermal properties, in addition to common safety considerations such as shock absorption and an anti-slip surface. Testing of materials properties should be performed by accredited labs.
- Avoid artificial grass and materials with a high solar absorption coefficient, as these reach the highest surface temperatures. Pfautsch et al. published a comprehensive, comparative analysis of materials in this regard[1]. For artificial, unshaded surfaces, it is advisable to use materials with a Solar Reflectance Index[i] (SRI) of no less than 29, in accordance with recommendations of the Green Building Council.
- For materials exposed to direct sunlight, select those with UV reflectance lower than 10%. Materials with a diffuse reflectance should be chosen (i.e., materials with a specular reflectance exceeding 20% should be avoided, in alignment with City of Parramatta Development Control Plan on Facades). Most materials reflect at least 5-8% of UV radiation regardless of their colour, while some white cement concrete surfaces may exceed 30% reflectance in the UV range. Bare metal surfaces must be avoided, due to their potential to reflect more than 50% of UV radiation. Coated metals are generally acceptable if the UV reflectivity remains below 10%. White coatings with titanium dioxide as a pigment can exhibit slightly higher reflectivity (up to 15% in the UVA, but this effect is mainly confined to the highest wavelengths).

Provision of shade

- Provide shade to equipment as well as to resting areas
- Prioritise shade over areas for toddlers, as they are mostly exposed to UV risk and thermal discomfort
- Carefully assess the UV transmittance of the shade sails with data provided by an accredited or reputable laboratory (tested according to AS4174). Sun shades should have an ultraviolet effectiveness (UVE) rating of 95+ (If tested according to AS4399, products should have an Ultraviolet Protection Factor UPF 50+).
- Follow the recommendations provided by the Benchmarking Shade in NSW playgrounds[2] project of Cancer Institute NSW:
  - At least 70% coverage of quality shade over play equipment and nearby seating, with at least 45% of this tree shade.
  - Ideally, trees should be to the east and west of playgrounds to offer the most shade throughout the day.
  - Community survey findings (386 respondents) were clear that playground users want more shade. Tree shade was generally preferred.
  - The combination of trees and built shade was found ideal for UV and heat protection.

---

[i] The SRI is a parameter computed with the solar reflectance and thermal emittance as inputs. The calculation is performed according to ASTM E1980. The solar reflectance can be measured according to ASTM E903, ASTM C1549, or ASTM E1918. The thermal emittance can be measured according to ASTM C1371.

Project Summary

Playing outdoors is a right of children, and it is especially important for those growing up in urban environments where access to nature is often restricted. Increasingly warmer summer temperatures, combined with a widespread lack of appropriate shade and the use of unsuitable materials to protect against solar ultraviolet radiation, will limit children's opportunities to use nearby playgrounds. This interdisciplinary project investigates the conditions under which play in public outdoor playgrounds across Western Sydney becomes unsafe due to the lack of shade and materials that become too hot, causing surface skin burns when touched. We combine environmental monitoring with assessments of occupancy and human thermal comfort to evaluate the quality and quantity of shade and thermal environments under benign summer conditions. Results identify thresholds at which playgrounds become too hot for play. We focus this pilot study on three playgrounds across Parramatta that differ markedly in how they are shaded and designed. Our findings will be used strategically to approach industry partners, government, and not-for-profit organisations to develop a larger, systematic research project that establishes basic principles for outdoor playgrounds to remain safe for children in warmer climates and consistently high UV radiation.

1. Project Aims & Background

Public playgrounds contribute to the life and development of local communities and urban sociality in multiple ways, both direct and indirect. First, public playgrounds offer access to outdoor play – an essential element for the physical and emotional development of children[3], regardless of family income. In Article 31 of the Convention on the Rights of the Child[4], the United Nations has declared that "Every child has the right to engage in play and recreational activities appropriate to the age of the child".

Further, the benefits of well-designed public play areas also provide space and opportunity for connection across genders, socio-economic status, and generations. Therefore, public playgrounds are an essential component of the urban social infrastructure[5]. However, the combination of global climate change and urban sprawl is worsening urban overheating[6,7], which in turn reduces the liveability of outdoor spaces[8]. Moreover, children are disproportionately affected by heat exposure at playgrounds[9], *mainly due to their high ratios of both metabolism-to-surface area, and surface-area-to-body-mass, resulting in thermoregulatory inferiority relative to adults during physical activity in hot conditions*[10]. At the same time, public playgrounds often exhibit the highest surface temperatures in a built environment, as documented in Phoenix, Arizona[10], which presents many features similar to Australian climates. This is a particular issue in Western Sydney. Surface temperatures in sun-exposed playgrounds in Western Sydney are often hot enough to burn skin due to insufficient provision of high-quality shade and inadequate materials used for flooring and equipment[1]. Multiple sources have reported serious burns after contact with hot surfaces at playgrounds[1,11]. Moreover, outdoor thermal comfort is influenced by dynamic thermal pleasure[12] and 'one-size fits all' thermal comfort models used during design stages do not capture the variability in the human thermo-physiological response[13]. Additionally, inadequate shading will increase the risk of overexposure to harmful UV radiation for children, as well as for parents and caregivers.
Public outdoor playgrounds are often located in areas with little or no shade. In 2024, assessments in Parramatta revealed that 10% of playgrounds have no shade at all over the main play area, and only 17% had shade covering more than 70% of the main play area[14]. This means that users are at risk of overexposure to ultraviolet (UV) radiation, which can result in sunburn and increased incidence of skin cancer[15].

Low levels of shade protection at outdoor playgrounds also mean that children and visitors frequently come into contact with hot surfaces, either on the ground surface and flooring or on pieces of play equipment. Temperatures above 50°C can cause severe skin burns in just a few seconds (ISO 13732-1)[16]. The temperature of sunlit surfaces varies notably with the type and colour of material, with natural materials, such as green natural grass, being cooler than synthetic fabrics, like soft-fall rubber. In the summer of 2020, dark blue and black rubber play equipment reached surface temperatures of 70-90°C in Cumberland, and black rubber flooring and green synthetic turf had surface temperatures exceeding 88°C at the playground in Bennalong Park[1].

Outdoor play can also lead to high levels of exposure to infrared radiation (radiant heat) and high air temperatures, which are the leading causes of heat-related illness[17]. Hot conditions also reduce perceived thermal comfort of visitors, which leads to shorter visitation lengths and discourages future visitation[18]. Some aspects of outdoor playground design can be modified to influence the surrounding local microclimate and thereby reduce overheating and improve thermal safety[19]. The use of bioclimatic design principles, which encompass vegetation, construction, and coating materials, can help increase usability and access to outdoor play opportunities, thereby maintaining the maximum opportunity to meet the right to play.

Substantial work with independent measurement campaigns focusing on or including playgrounds[1,7] and variability of shading[20] in Western Sydney has been carried out by this project team. Project investigators have collaborated with the community through two citizen science projects[21–23] and have built Australia's first UV-smart Cool Playground in Merrylands[24]. The research team has produced ample empirical evidence that the risks associated with hot surface temperatures and equipment, as well as the lack of UV protection in public playgrounds, are very real and widespread. However, there is no solid quantification of the reduction in the 'playability' of playgrounds. Moreover, the influence of various parameters, such as surface temperatures and shade (natural or artificial), on the actual use of playgrounds remains to be thoroughly investigated. The literature provides some analysis with direct observations of users in public spaces in childcare centres in winter conditions[25] and public spaces in hot and humid environments (including but not limited to playgrounds)[26], but no ongoing automatic measurements are reported, and none in Australia. Overall, the quantification of people's behaviour in outdoor places and its correlation with local environmental conditions is a rapidly expanding area[27], enabled by new sensing and data transmission technologies.

Scientific and social aims. The novelty of this project lies in addressing these research questions:

- How do quantity and quality of shade and the overall thermal environment affect playground use?
- Are there environmental thresholds for the summertime visitation of playgrounds?
- Which design solutions prolong playground use under a warming climate?

This report presents the results of all monitored playgrounds and is shared with City of Parramatta Council to support the improvement of existing facilities under the regular renovation plan and the design of climate-sensitive playgrounds for the future. The report is also shared with other local governments and stakeholders.

Within the scope. The project scope encompasses the comprehensive monitoring of radiative and thermal exposure at playgrounds, assessed through local measurements with scientific-grade sensors, as well as the smart detection of playground visitation and climate parameters. Technical recommendations and a prototype platform that integrates long-term monitoring and its impact on the design of playgrounds will be developed.

Out of the scope. A sociological analysis, including a representative sample of visitors with a record of their demographic profiles and interviews, is outside the scope of the project. Additionally, measuring the level of engagement (i.e., intensity of play) and social interaction of visitors at playgrounds as a function of environmental parameters is outside the scope. The social cohesion within a community linked to the quantity and quality of playgrounds will not be investigated either.

2. Methods

The project approach involves an experimental and quantitative assessment of representative playgrounds selected to address the research questions.

2.1 Selection of Playgrounds

Upon consultation with Parramatta City Council and local community groups (i.e., ParraParents[ii]), three playgrounds with similar design and equipment have been identified: Binalong Park, Doyle Ground, and WR Musto. These playgrounds have no shade (WR Musto), intermediate shade (Doyle Ground), and high-quality shade (Binalong Park), provided by trees or engineered structures, and are geographically close and, as such, subject to similar environmental conditions (Figures 1-5).

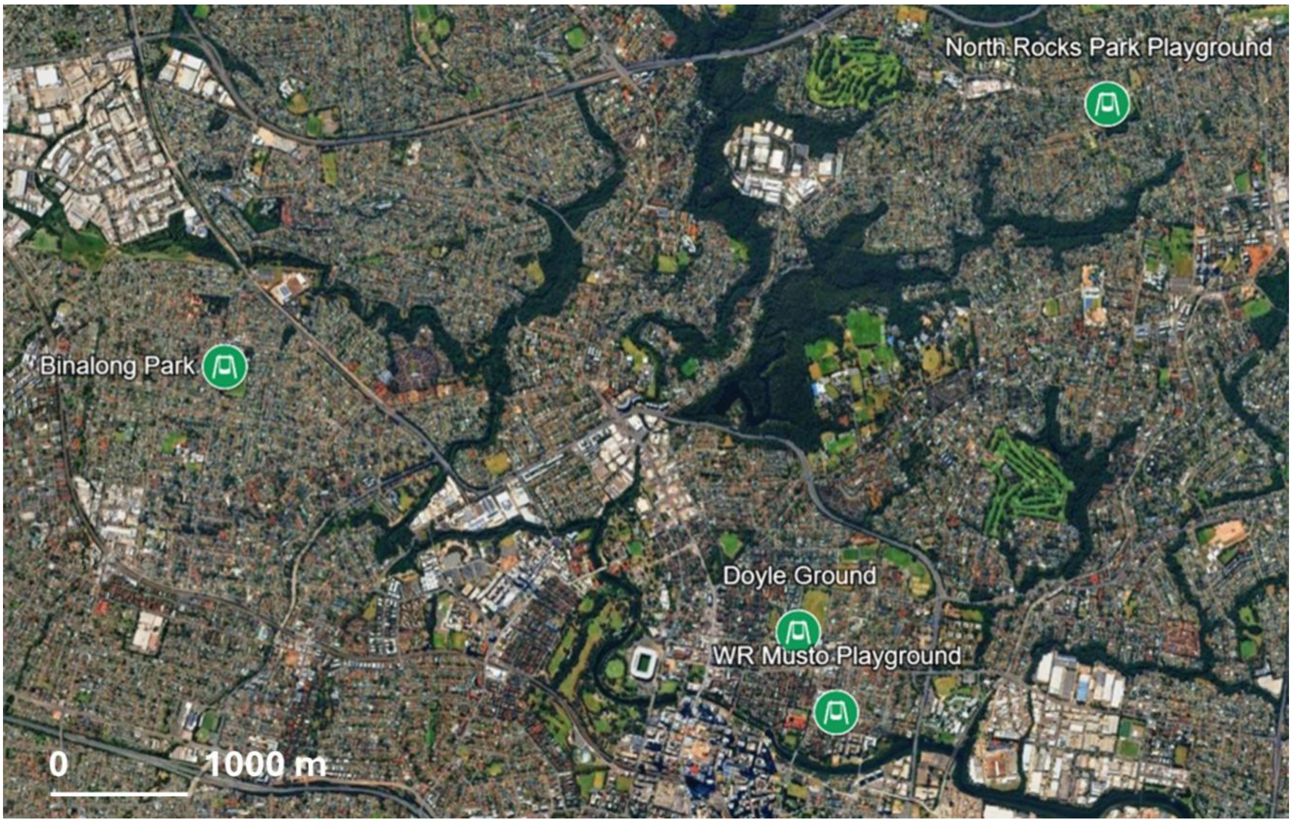


Figure 1. Location of the selected playgrounds (green swing symbol). Background map from Google Earth.

These playgrounds were selected after the inspection of eight playgrounds shortlisted by the Parks & Open Space Planning Team of City of Parramatta Council, in consideration of the requirement of gated playgrounds to be able to count access. Playgrounds were also selected in consideration of the criteria defined by Walters and Pfautsch[14].

Also, playground selection is informed by demographics, socio-economic status, and expected population served. A fourth playground was later selected to replace WR Musto in consideration of its renovation and to include a playground with greater visitation and limited natural shade[iii]. The North Rocks Playground was thus selected to represent a case without artificial shade and with limited natural shade (Figure 5). This fourth playground was included on 31 October 2024, after approval from Parramatta City Council.

[ii] ParraParents is an extension of the Parramatta District Mums Facebook group, a community group paying attention to and offering local information on the quality of playgrounds, parks, and other opportunities for outdoor play in Western Sydney https://www.parraparents.com.au

[iii] WR Musto upgrade project: https://participate.cityofparramatta.nsw.gov.au/wr-musto-playground-replacement

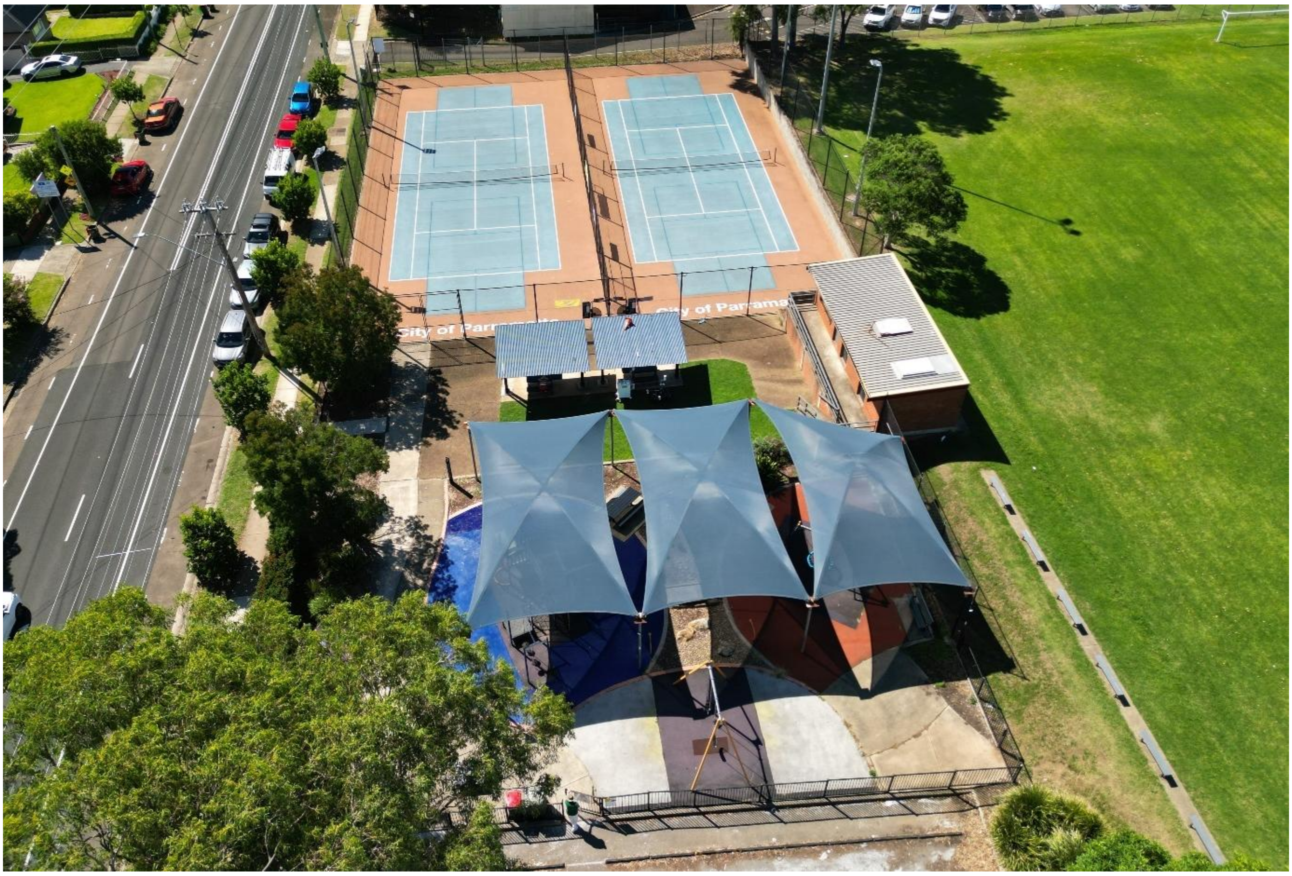


Figure 2. Binalong Park.

Figure 3. Doyle Ground Playground.

Figure 4. WR Musto.

Figure 5. North Rocks Playground.

2.2 Mid-term monitoring

In addition to short-term campaigns, continuous measurements include temperature and humidity dataloggers (MX2302A by HOBO, with ±0.2°C accuracy in temperature and ±2.5% for relative humidity) enclosed in a radiation shield (RS1 by HOBO), sampling data every 10 minutes. Hourly averages are then computed from the readings every 10 minutes. Data can be retrieved from the loggers via Bluetooth on-site (no remote connectivity) when inspecting the playgrounds.

Additional weather datasets are retrieved from weather stations of the Bureau of Meteorology (BOM) and air quality stations of the NSW Department of Climate Change, Energy, the Environment, and Water (DCCEEW), which collect at least hourly or semi-hourly data for temperature, humidity, and wind speed (Figure 6). The BOM stations are located out of the urban fabric at:

- Olympic Park (station 66212, Lat: -33.83379, Long: 151.07179).
- Horsley Park (station 67119, Lat: -33.851, Long: 150.8567).
- Bankstown Aerodrome (station 67113, Lat: -33.9181, Long: 150.9864).

The only urban station in the area is the Parramatta North weather and air quality station (Lat: -33.79944, Long: 150.99777) of the NSW DCCEEW, which is located approximately halfway between the Doyle Ground and Binalong Park playgrounds, and roughly in a barycentric position with respect to all four playgrounds (Table 1). Another urban station close to the area is the air quality station in Macquarie Park, also managed by the NSW DCCEEW. In addition to richer spatial representation, this approach using multiple stations from multiple networks ensures redundancy and quality control, as automatic weather stations are exposed to the risk of data loss (mostly due to data transmission failures). Reliance on networks of stations for quality control is a well-established practice[28–30].

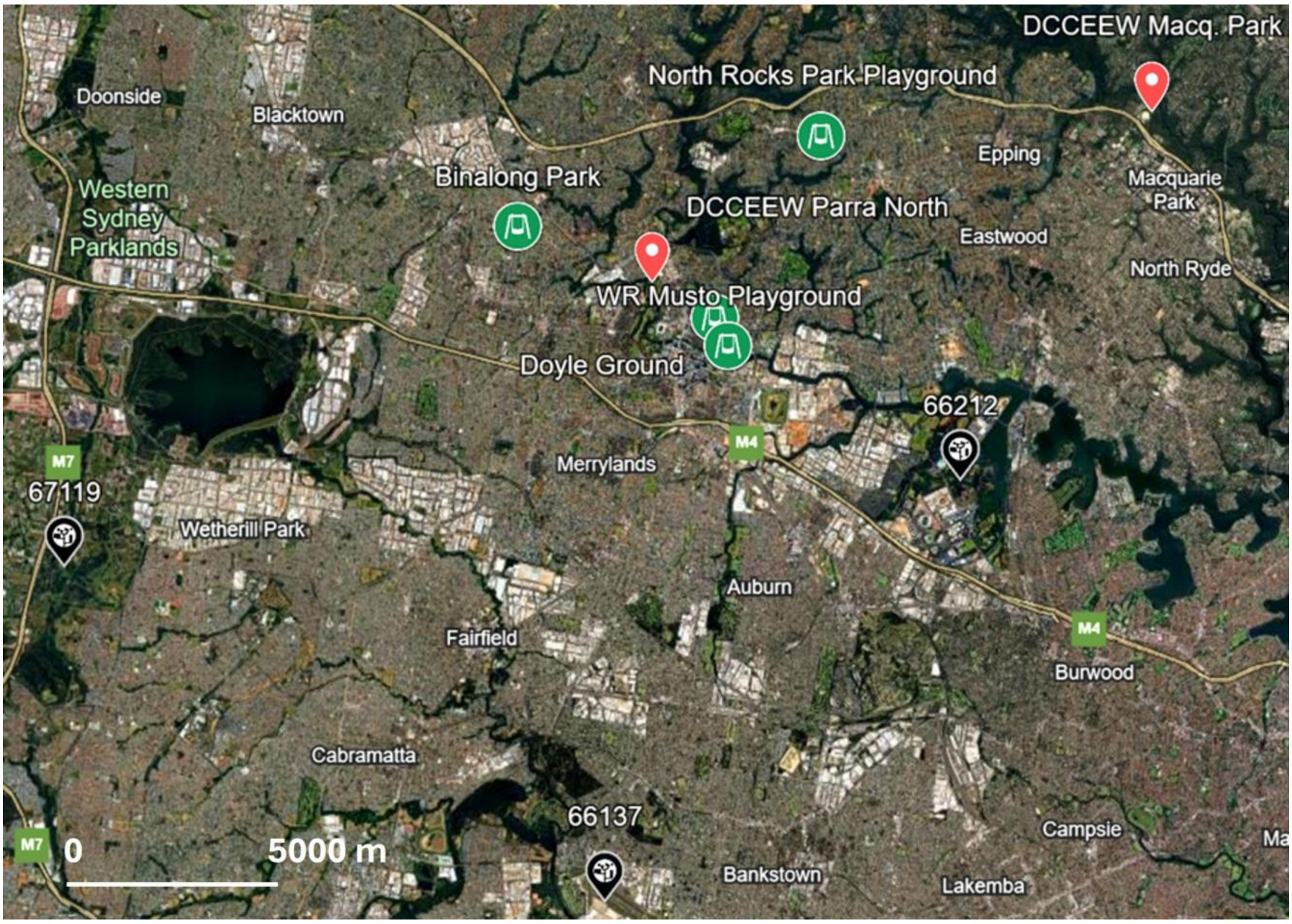


Figure 6. Location of the selected playgrounds (green swing symbol) in the Parramatta area, with the indication of the closest weather stations of the Bureau of Meteorology that supply semi-hourly data (black placemark symbol, 66212: Olympic Park, 67119: Horsley Park, and 67113: Bankstown) as well as an air quality station in Parramatta North and Macquarie Park, managed by DCCEEW – NSW Government (red placemark symbols). Background map from Google Earth.

Table 1. Distance (in km) between each site and the automatic weather stations in the area providing hourly or semi-hourly data for at least air temperature, humidity and wind speed and direction.

Site/Weather station	Parramatta North (DCCEEW)	Macquarie Park (DCCEEW)	Olympic Park (BOM)	Horsley Park (BOM)	Bankstown Airport (BOM)
Binalong Park	3.2	14.4	11.1	12.3	14.8
Doyle Ground	1.6	10.8	6.3	15.5	12.9
WR Musto	2.2	10.8	4.6	15.8	12.3
North Rocks	4.9	7.4	7.7	19.4	17.3

Access to playgrounds has been monitored with bi-directional infrared people counters by Farmo (Figure 7). The same system was used and recommended by the City of Melbourne. No images of people are collected: the sensors work like presence sensors in buildings or gate-opening infrared proximity sensors, and only record a count when a person or a group of persons transits across the field of view of the sensor. Data is inherently anonymous, and only the total count is recorded within 15 minutes.

The project has been granted ethics approval (IRECS4758), and stickers have been placed on the poles to which the sensors are fastened, along with information panels displayed at the gates, as per the ethics approval and agreement with City of Parramatta Council. The information panels and stickers contain the QR code to the project webpage and the short link to it (https://unsw.to/too-hot-to-play), as well as the names of the Lead CIs and project contacts, and the ethics approval number (Figure 7).

Temperature and humidity sensors, as well as gate-facing people counters, were installed on 27 February 2024. Additional equipment-facing people counters were installed on 15 August 2024 to increase data capturing and characterise playground activity beyond visitation. Sensors were installed at North Rocks Playground on 31 October 2024, following approval by Parramatta City Council to add this fourth site, following the decision by Parramatta City Council to renovate WR Musto. The equipment installed at each playground is detailed in the following section.

Figure 7. Information board (coreflute, UV-resistant ink), fastened to playground gates with plastic cable ties, and information stickers on the poles, under the sensors.

2.3 Sensor Installations at Playgrounds

Binalong Park (Old Toongabbie, Lat: -33.78809, Long: 150.96549). Sensors installed (Figure 8):

- Sensor 1 on pole in front of gate, close to the carpark (shade pole).
- Sensor 2 on the sign pole (temperature & humidity sensor remains on the fence).
- Sensor 3 is located on the pole near the sports field.
- Sensor 4 is next to the tennis court pole.
- Sensor 5 on an aluminium pole installed by UNSW, fastened to the fence (on the side of the carpark), with the sensor facing the gate.
- Sensor 6 is on the same pole as sensor 1, facing the swing.
- Sensor 7 on a canopy pole, facing the playground equipment (slide).

Figure 8. Sensors installed at Binalong Park.

Doyle Ground (North Parramatta, Lat: -33.80641, Long: 151.01281). Sensors installed (Figure 9):

- Sensor 1 on an aluminium pole installed by UNSW, fastened to the fence (Fennel St side).
- Sensor 2 and weather station (temperature and humidity sensor) on the shade pole (Butler St gate).
- Sensor 3 on the canopy pole, facing the swings.
- Sensor 4 on the canopy pole facing the playground equipment (castle).

Figure 9. Sensors installed at Doyle Ground.

WR Musto (Parramatta, Lat: -33.81193, Long: 151.01595)

There is no pole to install sensors and a people counter, other than the playground equipment. We installed a temporary pole, fastened to the fence, which will be removed after the project (Figure 10). The installed sensors include one people counter and one temperature and humidity logger.

North Rocks Park Playground (Carlingford, -33.77014,151.03565)

A total of five people counters were installed on 31 October 2024. One counter was installed per gate, on a pole connected to the playground fence. An additional three people counters were installed, facing the equipment, on poles fastened to the fence or existing poles at the playground. A temperature and humidity sensor, enclosed within a radiation shield, was installed on a pole connected to the fence, near the swing (Figures 11-13).

Figure 10. Sensors installed at WR Musto.

Figure 11. Gate-facing people counters are located on a pole connected to the fence at the gate near the tennis court (left) and near the entry close to the car park (centre), with a second counter facing the equipment on the same pole (another view in the picture on the right).

Figure 12. Equipment-facing people counters installed on a pole fastened to the fence near the swings (left) and on a sign pole near the carpark (right).

Figure 13. A temperature and humidity sensor installed on the same pole near the swing.

2.4 Short-term campaigns (intense measurement data collection)

Short-term campaigns for each playground include the measurement at multiple locations of temperature, humidity and wind speed (with MetPakPro weather stations by Gill) and mean radiant temperature, by measuring net-radiation (incoming and outgoing shortwave and longwave radiation, measured by Hukseflux NR01 net radiometers) along the three axes, to quantify thermal comfort conditions, following an internationally accepted method[31]. Moreover, the amount of incoming ultraviolet radiation in full sun and below the shading structures at playgrounds is measured to quantify the risk reduction of UV radiation damage to the skin. Both total UV radiation (by means of a CUV radiometer by Kipp and Zonen) and erythemal radiation, from which the UV-index is computed, were measured (with a UV-E radiometer by Kipp and Zonen). Data measured by the different sensors was logged every 15 seconds by a DT85 datalogger (by Lontek) and averaged over the observation period at each location. Surface temperatures were captured with an infrared camera (T860 by TELEDYNE FLIR).

A first version of the experimental setup was used in the pilot campaign (Figure 14), which evidenced difficulty in performing measurements at exactly the same spot with instruments on separate carts. The pilot campaign was conducted at three playgrounds on the same day (i.e., Doyle Ground, WR Musto, and Binalong Park), where the equipment was moved from one playground to another, and a single round of measurements was performed for all selected locations at each playground. A round of measurements took approximately 45 to 60 minutes.

Figure 14. Mobile experimental setup used to record data along transects and characterise the local thermal comfort conditions and incoming solar and ultraviolet radiation. On the left, MaRTy, a mobile biometeorological instrument platform capable of measuring air temperature, humidity, wind speed and direction, GPS coordinates and mean radiant temperature using data captured in six directions by six solar and six infrared radiometers. These parameters are used to compute the local thermal comfort conditions, simulating the way the human body experiences heat. On the right, a cart equipped with solar and UV radiometers, as well as two weather stations at 0.3 m and 1.8 m from the ground.

At each playground, measurements were recorded until the signal from the instrument was stable (typically at least 90 seconds) at various shaded and unshaded locations. The first campaign also demonstrated that a 90-second permanence per spot was sometimes insufficient to allow for the full stabilisation of the signal, especially in weak wind conditions and when transitioning from sunlit to shaded positions. Additionally, the pilot campaign involved transferring equipment from one site to another. This process limited the measurement time and exposed the instruments to varying conditions due to differences in cloudiness, which prevented us from achieving the initial goal of comparing the three selected sites on the same day. The results of the pilot campaign are included in the preliminary report, which is included in Annex B.

Therefore, a second, more compact evolution of the experimental setup was used in the primary campaigns during the summer of 2024/25, with all instruments on the same cart (Figure 15). Measurements were performed for at least 5 minutes per location, after a 1-minute signal stabilisation period. Additionally, the measurement approach was modified to perform measurements at one playground per day, with multiple measurements taken throughout the day during the hottest hours. The use of weather stations at multiple heights was discontinued due to technical constraints, including the stability of the cart and data logging. The refinement of this aspect will be the scope of further development of the experimental setup and future research. Thus, after the pilot campaign, we organised single-day campaigns for each of the following three playgrounds: Binalong Park, Doyle Ground, and North Rocks Playground. At each playground, measurements were collected for each identified spot at least every hour, during the central hours of the day. Measurements were not collected during the late afternoon or evening hours to avoid disrupting the use of the playgrounds by children engaging in outdoor play during the coolest hours of a hot day.

Figure 15. New version of the MaRTy mobile biometeorological instrument platform, including weather stations, net radiometers and UV radiometers.

As mentioned, each playground was preliminarily inspected with a thermal camera, and relevant cool and hot spots were identified, including shaded and unshaded locations. The measurement spots were marked to ensure that measurements were always collected at the same locations. Measurements with the thermal camera included additional locations, which covered all surface materials present at each playground in both shaded and unshaded positions. The surface temperatures of the shaded and unshaded pairs of materials were also measured every hour, in sync with radiation and albedo measurements. The measurement locations for each playground are given in Figures 16-19.

Figure 16. Measurement locations at Binalong Park Playground. Position 1: Dark rubber, unshaded. Position 2: Dark rubber, shaded. Position 3: Blue rubber partially shaded. Position 4: Grass unshaded. Position 5: Concrete unshaded.

Figure 17. Measurement locations at Doyle Ground. Position 1: White concrete (pathway), unshaded. Position 2: Teal rubber, shaded. Position 3: Teal rubber, partially shaded. Position 4: Mulch/soil, partially shaded. Position 5: Teal rubber, unshaded.

Figure 18. Measurement locations at WR Musto. Position 1: Artificial turf, unshaded near castle. Position 2: Mixed concrete and artificial turf, partially shaded near bench. Position 3: Artificial turf, unshaded near swing.

Figure 19. Measurement locations at North Rocks Playground. Position 1: Green rubber, unshaded. Position 2: Concrete, partially shaded. Position 3: Grass, shaded. Position 4: Concrete, unshaded. Position 5: Grass, unshaded. Position 6: Green rubber, unshaded.

2.5 Albedo measurements

To complete the characterisation of the playgrounds, we measured the albedo (i.e., solar reflectance) of the different surfaces at the selected playgrounds. Albedo can be measured with an albedometer, i.e., two back-to-back solar pyranometers measuring the incoming and reflected solar radiation in the 280-2800 nm wavelength range, following ASTM E1918[32]. The albedo is given by the ratio of the reflected radiation (measured by the lower dome) to the incoming solar radiation (measured by the upper dome). The measurements require clear sky conditions, no moving shadows (or people) in the measurement area, and a solar elevation of at least 45°.

If the instruments are positioned at 0.50 m over the surface, an area of 4 m x 4 m is sufficient to characterise the albedo, without a significant influence of other surrounding surfaces, since the view factor from the instrument to the area to be measured is approximately 95%. However, playgrounds typically display a patchwork of different materials and colours with irregular shapes of much smaller size than 4 m x 4 m. Thus, we used a variant of the ASTM E1918, known as ASTM E1918A, as described by Akbari et al. (2008)[33]. This variant enables the measurement of a smaller area, specifically 1 m x 1 m. To implement this variant, it is necessary to use two 'masks' of known solar reflectance, each of 1 m x 1 m. In this case, we selected materials as spectrally flat as possible and as Lambertian as possible, thus with a negligible specular component: a white expanded polystyrene panel and a black-painted plywood panel. We measured their reflectance in the laboratory using ASTM E903[34] (Figure 20). Once on site, measurements are performed using two back-to-back SMP11 pyranometers by Kipp & Zonen, which have a response time of 2 seconds for 95% of the signal (ISO secondary standard). Data are logged with a DT80 datalogger (by Lontek). Data are collected for 1 minute with the white over the black mask, then, with the black mask only and finally without any mask over the target (Figure 21). By using a simple linear interpolation formula, it is then possible to compute the albedo of the area underneath the masks, R_t, as:

$$R_t = \frac{I_3 - I_2}{I_2 - I_1}\left(R_w - R_b\right) + R_b$$

Where:

I_1	[W m^{-2}]	Irradiance measured with white mask over target
I_2	[W m^{-2}]	Irradiance measured with black mask over target
I_3	[W m^{-2}]	Irradiance measured from target surface
R_w	[-]	Reflectance of the white mask (measured in the lab)
R_b	[-]	Reflectance of the black mask (measured in the lab)

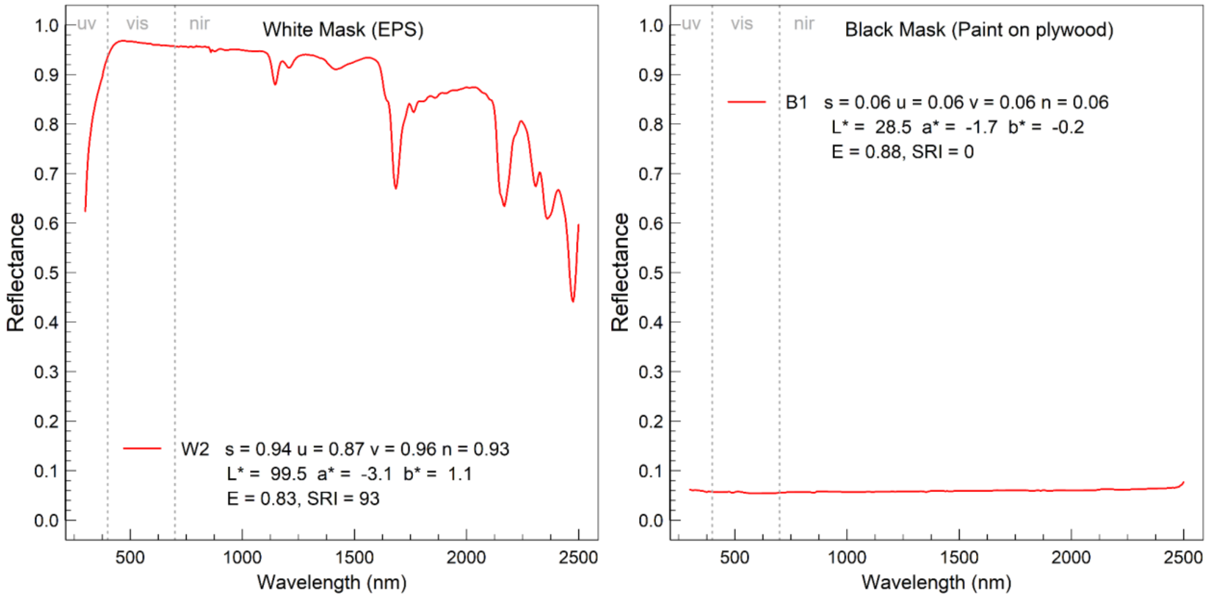


Figure 20. Spectral solar reflectance for the white mask (EPS) and black mask (black painted plywood) and broadband solar (s), ultraviolet (uv), visible (v) and near infrared (n) reflectances. L, a, and b provide the colorimetric coordinates in the CIELab space, while E and SRI are the thermal emittance and solar reflectance index, respectively.

Figure 21. Albedo measurements with the albedometer at 0.50 m over the white mask (left), the black mask (centre), and without masks (right), as shown over different surfaces to demonstrate the method's application over various patches.

Since it is a commonly used metric in environmental rating protocols, the Solar Reflectance Index (SRI) of the playground surface for medium wind conditions has also been computed following ASTM E1980[35]. As input data, we used the measured albedo and assumed an emissivity of 0.95, which is appropriate for non-smooth surfaces (as it is not technically possible to measure emissivity on-site over the whole thermal range, following ASTM C1371[36] or other reliable methods[37,38]).

3. Results and Discussion

3.1 Local climate at the playgrounds

The local climate at the playgrounds is a result of the design of the playground and the immediately surrounding built environment (microscale influence), as well as urban climate and overall regional climate conditions. The temperature and humidity sensors placed at the playgrounds provide an appraisal of such conditions.

Results over the period November 2024 – March 2025 (summer months plus one month before and after) show that the four playgrounds experience comparable local climate conditions, with the median air temperature over the period equal to 22.7 °C for WR Musto, 22.4 °C for Doyle Ground, 22.3 °C for Binalong Park, 21.5 °C for North Rocks Playground, and 22 °C for Parramatta North (DCCEEW). Also, the 99th percentiles of the air temperatures over the same period are comparable and equal to 36.1 °C for Binalong Park, 36.1 °C for WR Musto, 35.4 °C for Doyle Ground, 35.2 °C for North Rocks Playground, and 35.5 °C for Parramatta North (Figure 22).

The median of the average of the four sites is equal to 22.2 °C, which is only 0.2 °C warmer than Parramatta North. As the nominal accuracy of the temperature sensors used is ±0.2 °C, and that of most sensors used in automatic weather stations is also ±0.2 °C, differences between single readings of less than 0.4 °C cannot be considered significant. The median of the average of the four sites is, instead, 0.4 °C warmer than the average of Olympic Park and Horsley Park, i.e., the two Bureau of Meteorology stations to the east and west of Parramatta. At the same time, Bankstown, located further south in a relatively built-up area, has a median temperature of 22.2 °C. The 99th percentile for the average of the four playgrounds is instead 35.6 °C (nearly the same as Parramatta North) or 1.3 °C warmer than the average of Olympic Park and Horsley Park (i.e., 34.3 °C), or 1 °C warmer than Bankstown Aerodrome.

Among the four playgrounds, North Rocks Park Playground is the coolest, but still warmer than Macquarie Park or Olympic Park. The humidity ranges at the four playgrounds are also comparable, while Horsley Park and Bankstown are drier than all other locations (Figure 22). In this case, Parramatta North is drier than any of the other playgrounds.

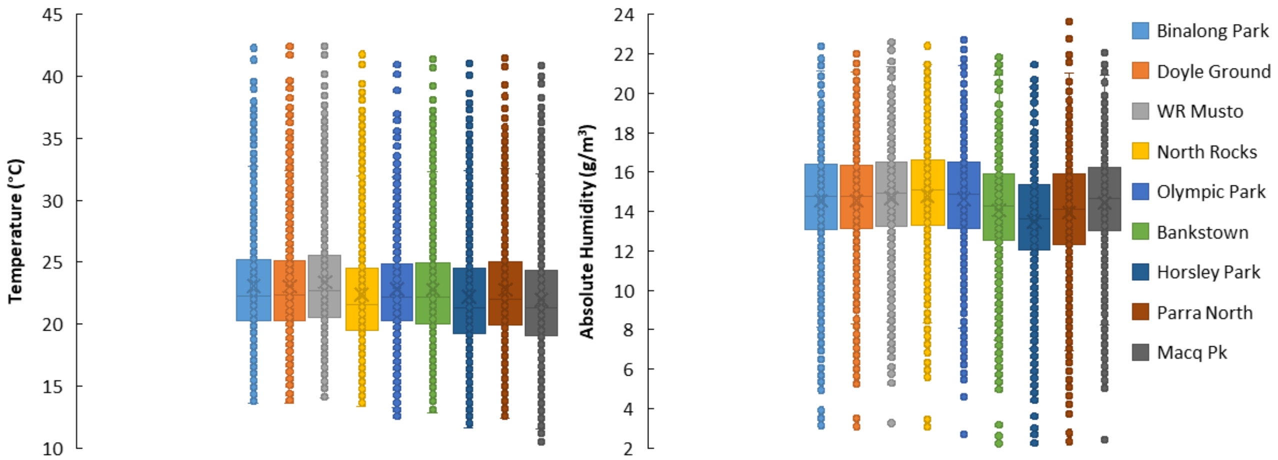


Figure 22. Boxplot of the average hourly air temperature (left) and absolute humidity (right) at the four monitored playgrounds between November 2024 and March 2025, as well as at the three closest weather stations of the Bureau of Meteorology that provide at least semi-hourly data (i.e., Olympic Park, Bankstown Airport and Horsley Park).

As the different sites and hours have varying temperatures, a direct comparison of relative humidity is not possible; therefore, the absolute humidity in g/m³ has been computed using the well-known psychrometric relations. All locations present a median absolute humidity of 14 g/m³ over the November-March period, with a 99th percentile of 19 g/m³, except for Bankstown and Horsley Park, which are substantially drier.

As different locations may be exposed to varying airflow or passing clouds with a delay, it is more appropriate to consider a 6-hour moving average for comparing the different sites. In this case, WR Musto is on average 0.41 °C warmer than the four-site average, North Rocks is 0.60 °C cooler, and Binalong Park and Doyle Ground are very close to the average (+0.12 °C and +0.07 °C, respectively) during the period from November 2024 to March 2025.

Beyond the statistical analysis, an appraisal of local conditions can be made by considering a sequence of hot and very hot days. For instance, observing the hourly temperature from 26 to 28 January 2025, we can see the build-up to a hot spell (Figures 23 and 24). On a warm day such as 26 January 2025, the peak temperature at the four playgrounds is within ±0.2 °C (with a maximum of 27.8 °C for the four-site average), which is the same as the nominal accuracy of the sensors and thus negligible. Then, the peak for the average of the four playgrounds is 0.8 °C warmer than the average of Olympic Park and Horsley Park, and 0.9 °C warmer than Parramatta North (Figure 24).

On a hot summer day such as 27 January 2025, when the peak daily temperature for the four-site average reaches 34.5 °C, the differences between different playgrounds are of the order of ± 1.2 °C, and 1.7 °C warmer than the Olympic Park – Horsley Park average, and 0.2 °C cooler than Parramatta North (which is not a significant difference). In these conditions, Binalong Park is the hottest, reaching 37.6 °C, while Doyle Ground and North Rocks are the coolest sites, at 35.3 °C and 35.5 °C, respectively. These patterns demonstrate an evident influence of the local microclimate during the build to heatwave/hot spell conditions, consistent with the literature[39–41].

The air temperature at Horsley Park is significantly warmer than at Olympic Park or Bankstown Airport, as the western side of Parramatta feels a more decisive influence than the eastern side of the effect of warm advection from inland, which prevails over the influence of the sea breeze during heatwave days.

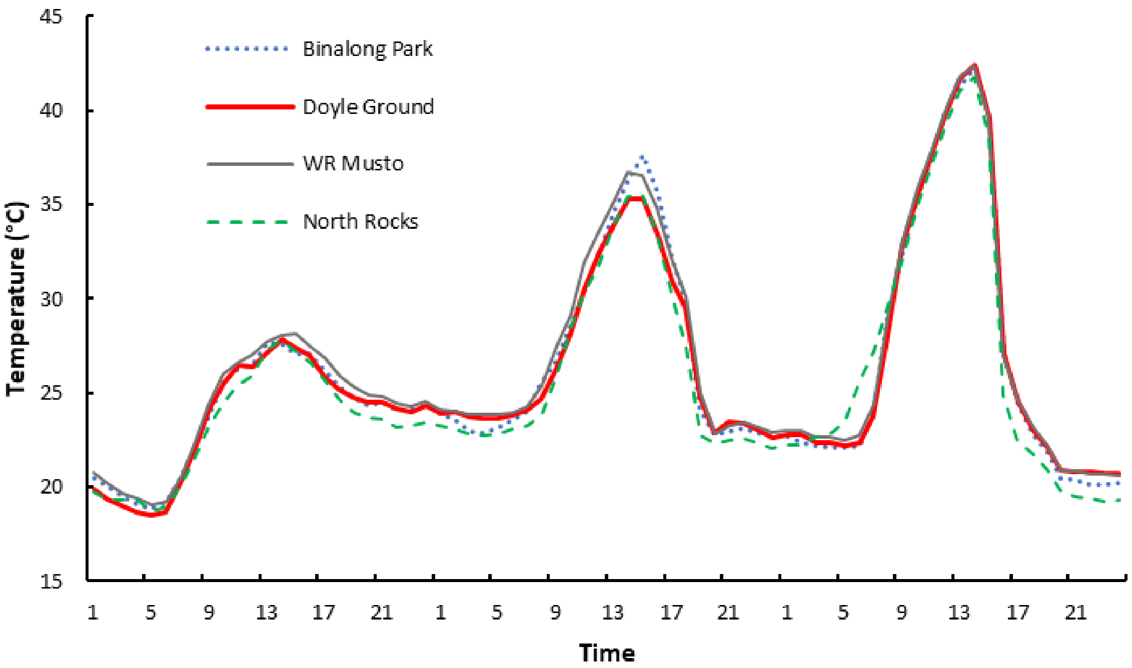


Figure 23. Average hourly air temperature at the four monitored playgrounds from the 26th to the 28th of January 2025. Local time is solar time (UTC+10).

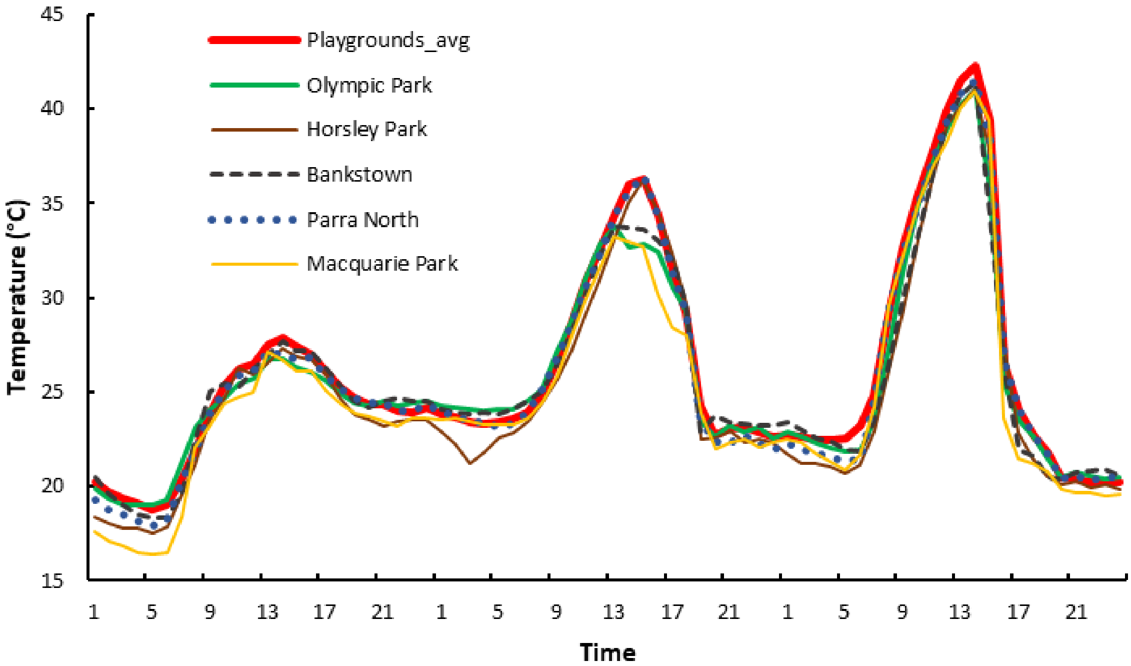


Figure 24. Average hourly air temperature for the average of the four monitored playgrounds and the Bureau of Meteorology stations of Olympic Park, Bankstown Aerodrome, Horsley Park and DCCEEW stations of Parramatta North and Macquarie Park from the 26th to the 28th of January 2025. Local time is solar time (UTC+10).

In fact, the coolest playground in the late afternoon (North Rocks) is also the easternmost and the one with the highest elevation (i.e., ~124 m, while Binalong Park is at 40 m and Doyle Ground and Musto are at ~15 m), thus subject to adiabatic cooling, which normally causes a ~0.65 °C temperature drop for every 100 m increase in elevation in the lower atmosphere[42]. The third day in this sequence is one of the hottest days during the measurement period, reaching a peak daily temperature of 42 °C (four-site average) with all playgrounds within ±0.3 °C, and 1.2 °C warmer than BOM stations (in this case also showing results within ±0.2 °C across the three BOM sites) and 0.7 °C warmer than Parramatta North. In this case, the hot front from inland prevails over the entire local government area, and no significant differences are observed between different sites.

To compare the humidity at different sites, we cannot directly plot the relative humidity, as not all sites are at the same temperature. A site at a higher temperature would show lower relative humidity than a site at a lower temperature for the same absolute humidity in the air. Therefore, the comparison between sites can only be made considering the absolute humidity (Figures 25-26). To facilitate comparison, we also include plots of the relative humidity, recomputed from the absolute humidity, for the hourly four-site average temperature (Figures 27-28).

The playground at North Rocks Park is slightly more humid than the other playgrounds, as the area is not far from several creeks and has good to average tree canopy cover[14]. Previous capillary data collection in the Parramatta Local Government Area documented the spatiotemporal variation of heatwaves, with a cooler eastern part and a warmer western part of the City of Parramatta Council area, and more heatwave days than if considering the weather stations of the Bureau of Meteorology.

Therefore, from the point of view of the monitoring of temperature and humidity, we can conclude that the continuously operated automatic weather station that is most representative of the local conditions for most of the playgrounds in Parramatta's LGA is the DCCEEW station of Parramatta North. Nonetheless, local measurements collected with sensors deployed at the playgrounds provide more detailed information, which needs to be compared with other data, such as visitation. Moreover, some playgrounds, such as Binalong Park, may be exposed to higher temperatures than playgrounds in cooler suburbs during very hot days (Figure 23).

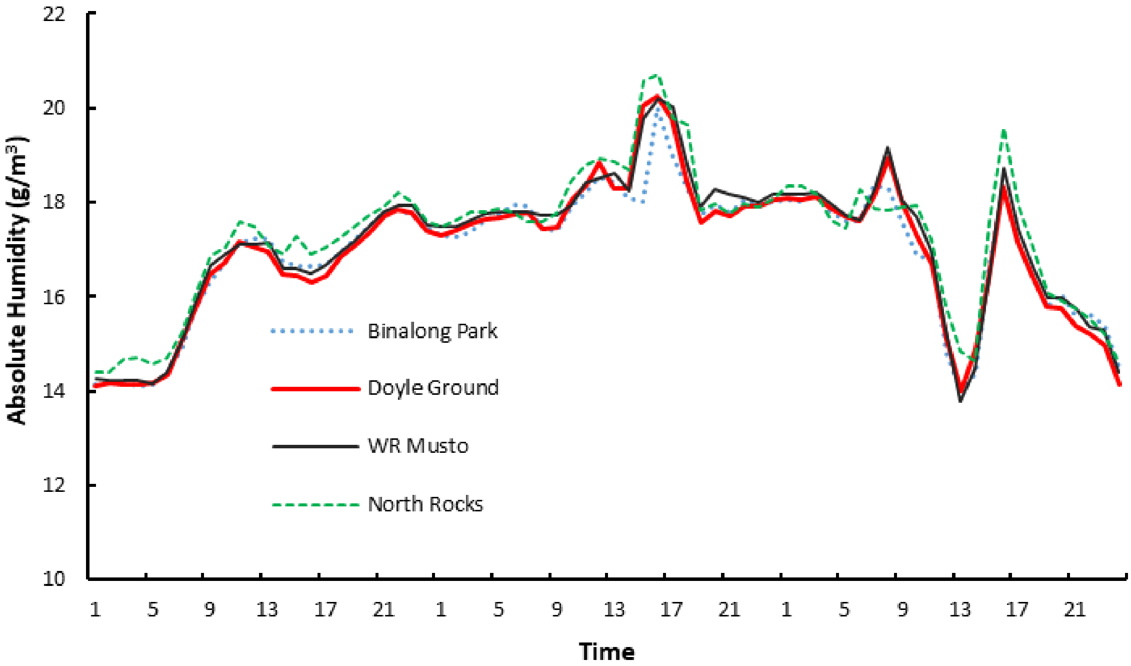


Figure 25. Average hourly absolute humidity at the four monitored playgrounds from the 26th to the 28th of January 2025.

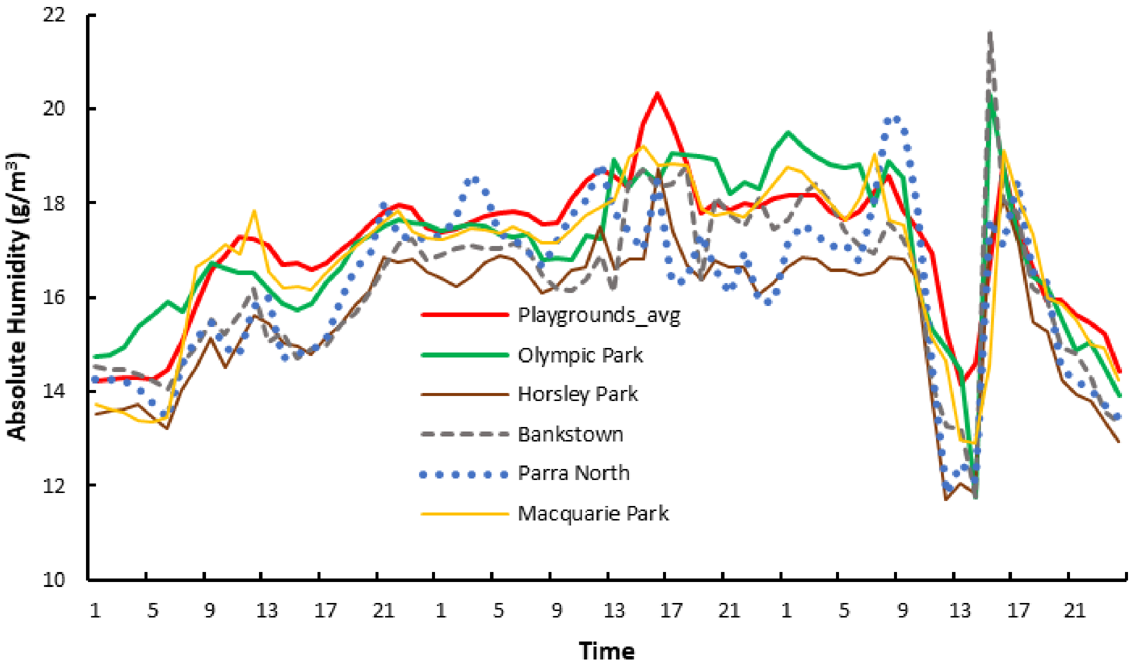


Figure 26. Average hourly absolute humidity for the average of the four monitored playgrounds and the Bureau of Meteorology stations of Olympic Park, Bankstown Aerodrome and Horsley Park, and DCCEEW stations of Parramatta North and Macquarie Park from the 26th to the 28th of January 2025. Local time is solar time (UTC+10).

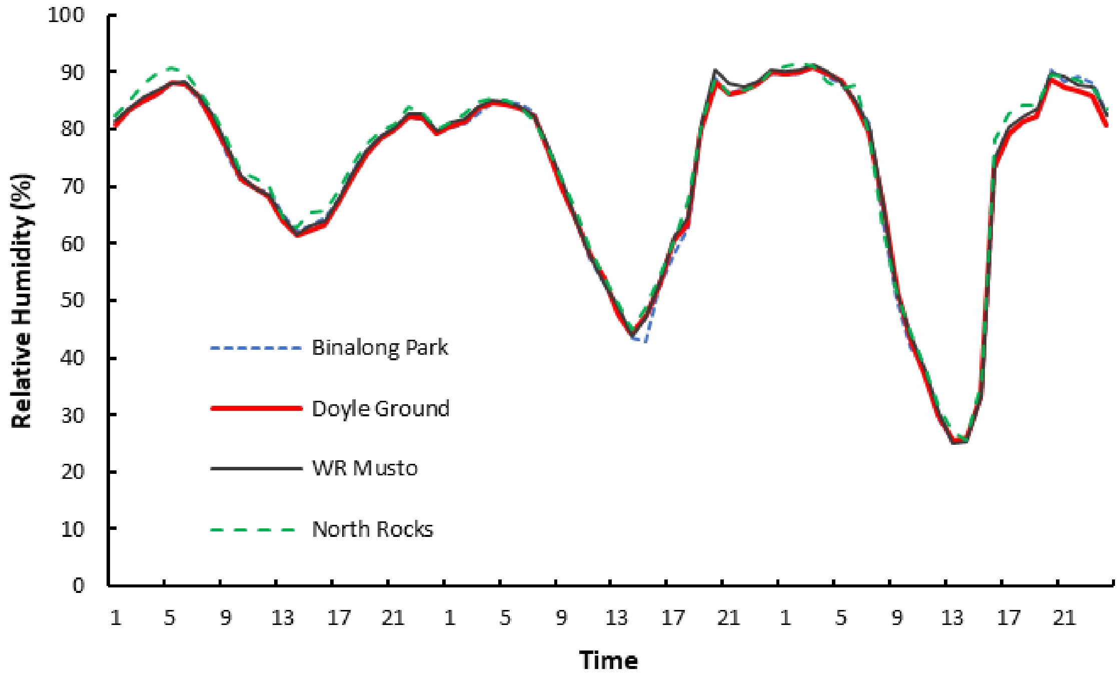


Figure 27. Relative humidity at the four monitored playgrounds (computed from the absolute humidity for the average playground temperature) from the 26th to the 28th of January 2025. Local time is solar time (UTC+10).

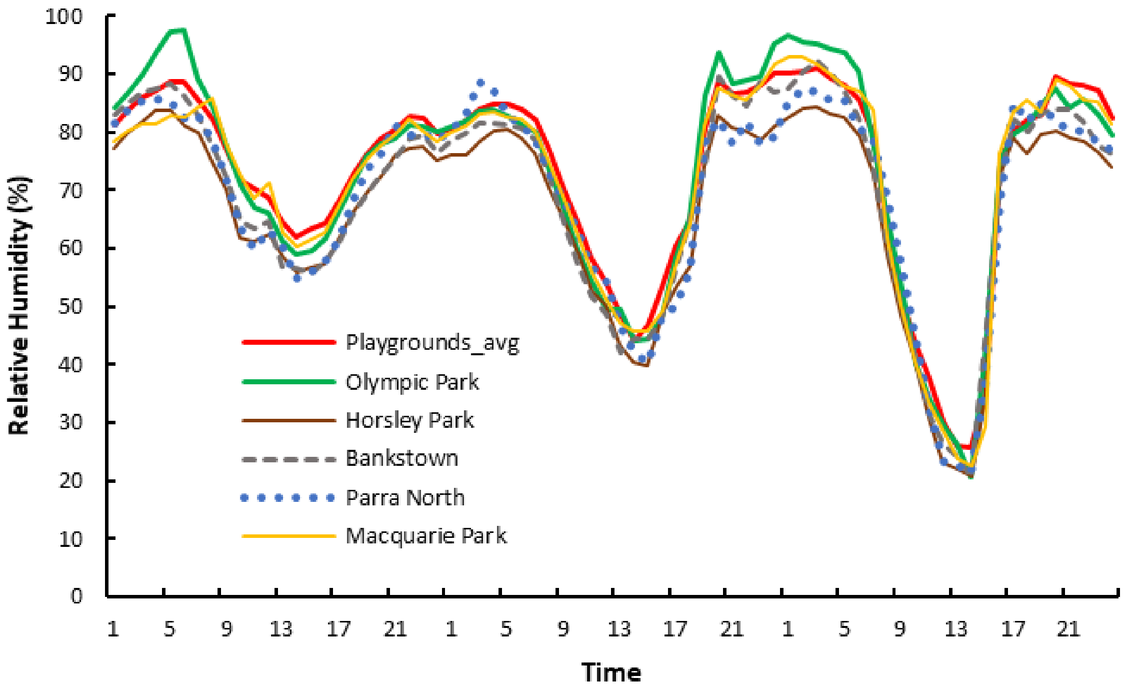


Figure 28. Relative humidity for the average of the four playgrounds and the BOM stations of Olympic Park, Bankstown, and Horsley Park and DCCEEW stations of Parramatta North and Macquarie Park (recomputed from absolute humidity from the average playground temperature) for the 26-28 January 2025. Local time is solar time (UTC+10).

A first appraisal of the cumulative heat exposure at the different sites can be obtained by computing the number of hours that exceed a threshold temperature (Figures 29 and 30). The average of the four playground sites presents only 32 more hours above 28 °C, 8 more hours above 35 °C and 4 more hours above 37 °C than Parramatta North (DCCEEW), while it presents 77 more hours above 28 °C, 25 more hours above 35 °C and 11 more hours above 37 °C than the average of Olympic Park and Horsley Park.

Further, all playgrounds are warmer for longer than any station of the Bureau of Meteorology (Figures 29 and 30). In particular, Binalong Park and WR Musto are systematically warmer for longer than North Rocks Park (i.e., 61 and 57 hours vs 41 hours above 35 °C). The hours above 40 °C, instead, are the same at any location, urban or not, which reflects the dynamics discussed for the hot and extremely hot days (Figures 23 and 24).

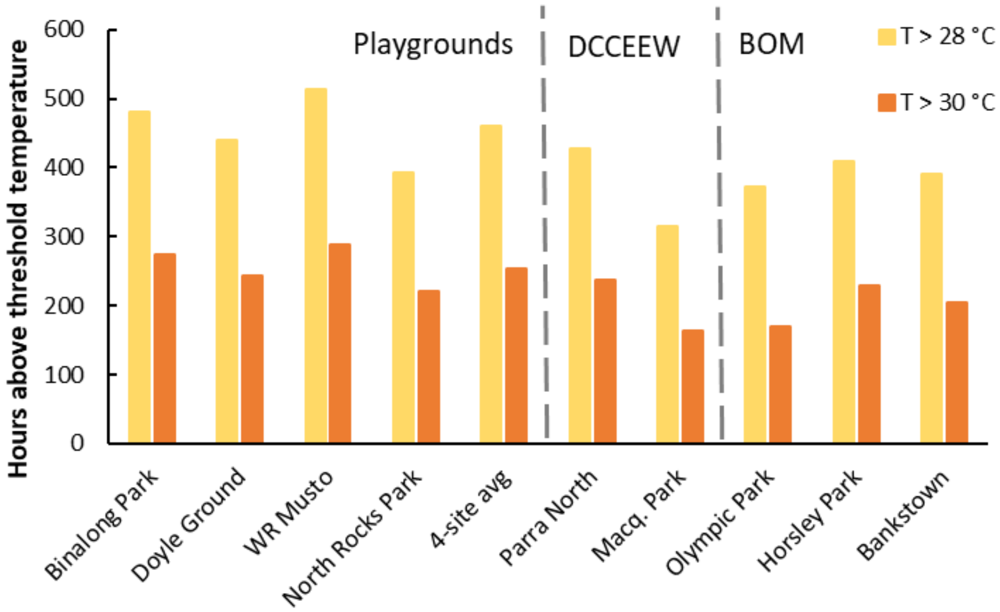


Figure 29. Number of hours above 28 °C and above 30 °C at the four monitored playgrounds and the Bureau of Meteorology stations of Olympic Park, Bankstown Aerodrome and Horsley Park from November 2024 to March 2025.

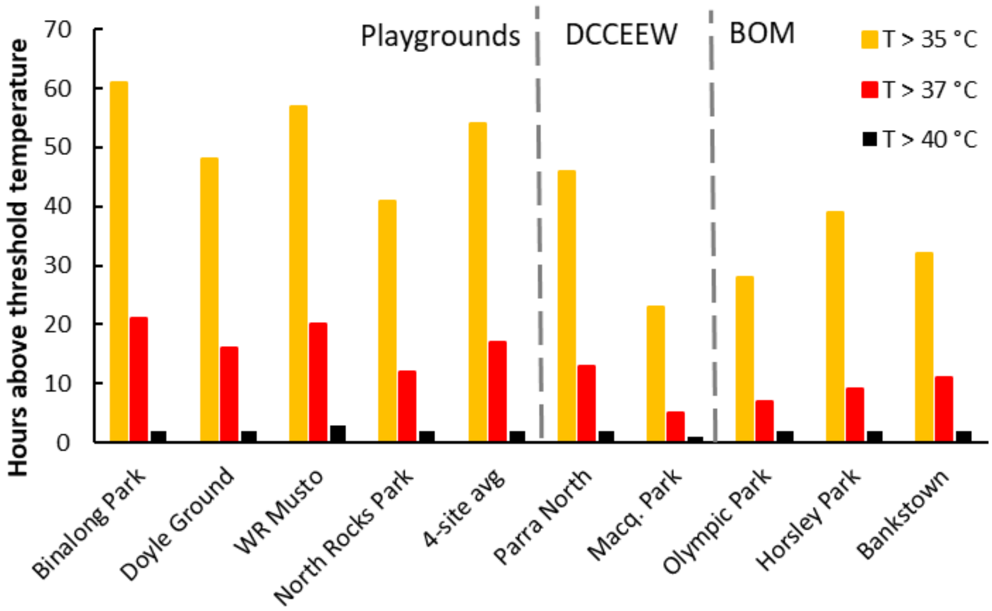


Figure 30. Number of hours above 35 °C, 37 °C, and 40 °C at the four monitored playgrounds and the Bureau of Meteorology stations of Olympic Park, Bankstown Aerodrome and Horsley Park from November 2024 to March 2025.

3.2 Playground visitation and activity as a function of temperature

After a first trial period and the testing of different sensor positioning, we achieved the final configuration for all four playgrounds. We collected data over the hot period from November 2024 to March 2025 (summer months, plus one month before and one month after). The gate-facing sensors provide information on access to the playgrounds, while the equipment-facing sensors describe the intensity of the activity. Overall, we observe a good correlation between local temperatures and playground visitation or playground activity (Figures 31 and 31). Obviously, the equipment-facing sensors record more counts as they capture children actively using the equipment.

Data from the gate-facing counters was also capturing some activity within the playground in the field of view of the sensor, with outliers as high as 800 counts per hour (at Binalong Park). Therefore, we excluded data beyond the 95th percentile of the gate counts, which is equal to 56. That is already a high number, considering 56 transits per gate within one hour as a threshold. Also, these outliers were detected only for some sensors that had play or sitting areas within their field of view. This issue may be overcome in the future with narrow-view sensors. However, the overall trends are captured well, and the core of the dataset is not significantly impacted by this technical limitation in sensor selection. In fact, other commercially available infrared sensors can capture transit across a gate without uncertainty, but at a cost more than 10 times higher. Visitation to Binalong Park and Doyle Ground playgrounds is concentrated in the 18-32 °C temperature range, while it declines more rapidly after 30 °C at North Rocks (Figure 31). Counts of gate crossings at WR Musto confirm the limited access to this playground, which led us to include North Rocks Park playground in the study, beyond the retrofit plans for WR Musto (Figure 32). Furthermore, WR Musto presents a marked asymmetry between weekday and weekend access, whereas all other playgrounds exhibit similar access patterns throughout the week.

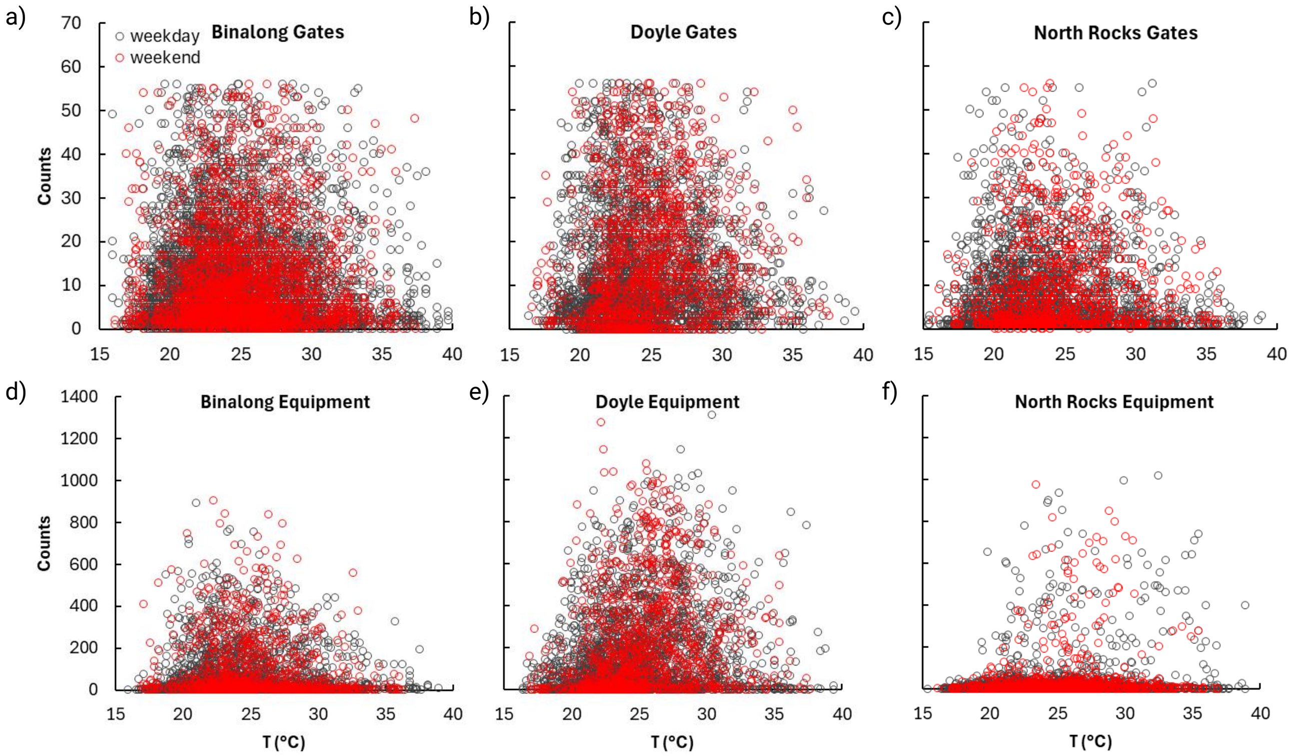


Figure 31. Counts by the gate-facing and equipment-facing sensors at Binalong Park, Doyle Ground, and North Rocks Park as a function of the hourly mean local air temperature (measured by the temperature dataloggers on site).

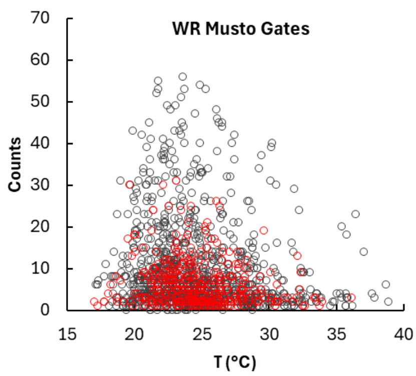


Figure 32. Counts by the gate-facing sensor at WR Musto as a function of the hourly mean local air temperature (measured by the temperature datalogger on site).

By separating the counts from sensors pointing at different types of equipment (i.e., swings, castle/climbing equipment and slides) and comparing Binalong Park and Doyle Ground, we can see that shaded equipment shows higher activity than unshaded equipment, with greater density of high-count numbers above 30 °C, especially for swings (Figure 33). However, in all cases, the decline in activity above 30 °C is sharp. North Rocks Park playground presents a case of equipment (a castle with a slide) in a partially shaded position, with remarkably higher activity than totally unshaded swings (Figure 33c,f). While the sensors pointing at the castle & slide at North Rocks might capture some foot traffic across the playground towards the tennis court, which we observed during site inspections, the high counts can only be justified by playground activity. For all playgrounds, high-intensity activities, such as the use of swings, appear to decline more steeply with increasing temperature than for other equipment.

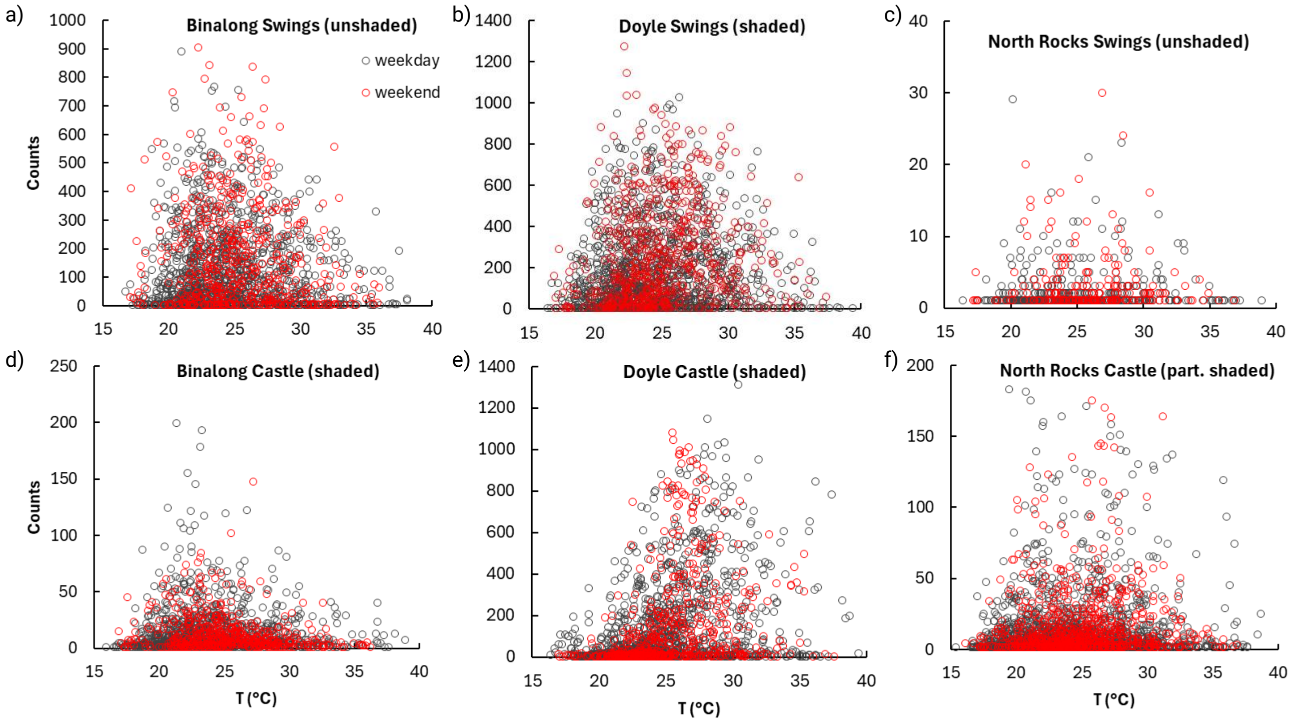


Figure 33. Counts by sensors facing swings and different types of equipment (i.e., castle + slides) at Binalong Park, Doyle Ground, and North Rocks Park as a function of the hourly mean local air temperature (measured by the temperature dataloggers on site). For the equipment at North Rocks (sublot f), it is a zoomed-in view of the data, excluding outliers. To facilitate visualisation, in this case, the subplots have different scales on the vertical axis.

As mentioned in the introduction and addressed in the literature[14], playgrounds are characterised by a bespoke design of equipment and shade, with many combinations of similar types of surfaces and equipment. Furthermore, they are located in different areas, which may result in slightly different demographics and preferences. Therefore, a direct quantitative comparison between different sites is difficult, and it is more meaningful to consider the baseline for each playground and how patterns change in different temperature ranges. This can be done by considering the probability density function of each playground in relation to the local temperature. As is known, the cumulative probability density equals 1. Therefore, we can see that at playgrounds without shading (or with limited shade), the peak of the activity is centred around a lower temperature interval than for playgrounds with good shade (Figure 34). Considering the 95% probability (count-weighted) temperature range for each of the four playgrounds, which represents the 95% central coverage interval of the probability distribution, we can synthetically describe when most visitation occurs.

For WR Musto, visitation occurs within a narrower temperature range than for any other playground (from 19.5 °C to 31.9 °C), with a peak at 22.5 °C. At North Rocks Park, visitation peaks at 22.2 °C, but it extends over a broader range (from 18.2 °C to 32.2 °C). For Doyle Ground, visitation peaks at 23.8 °C, with 95% of visits between 19.3 °C and 32.4 °C. Finally, Binalong Park shows a peak in visitation at 23.5 °C, with 95% of visitation counts occurring between 18.8 °C and 33.5 °C, thus in a 14.7 °C range, or 2.3 °C more than WR Musto (Figure 34). Considering the playground activity represented by the counts of equipment-facing sensors, the picture is less straightforward (Figure 35). In this case, 95% of the activity happens in a slightly wider range at Doyle Ground (from 19.9 °C to 33.0 °C) than at Binalong Park (from 19.3 °C to 32 °C), while the widest range is at North Rocks Park (from 19.8 °C to 35.5 °C), although with a significantly total count than in the previous two cases (Figure 33d,e,f).

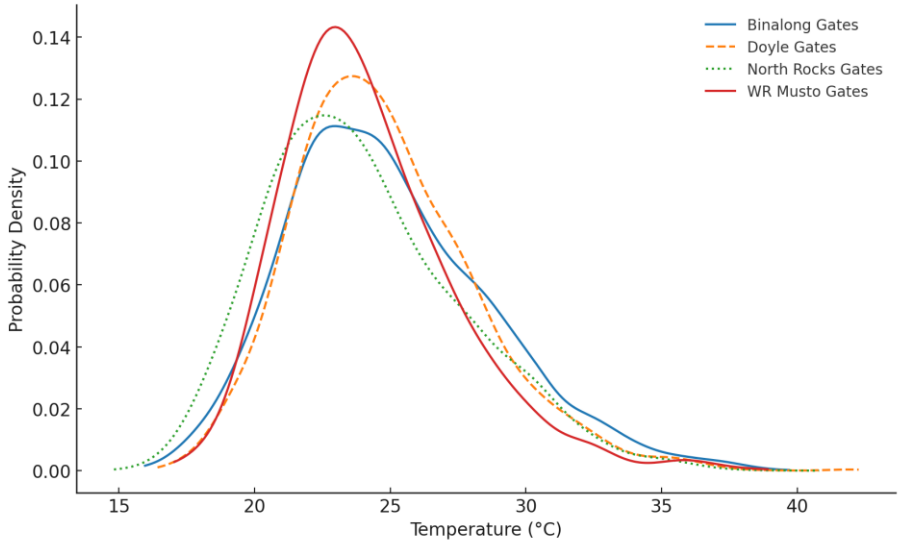


Figure 34. Counts by the gate-facing and equipment-facing sensors at the three monitored playgrounds as a function of the hourly mean local air temperature (measured by the temperature dataloggers on site). Here, the probability density is computed with a kernel density estimation, using a Gaussian, with a 0.5 °C width.

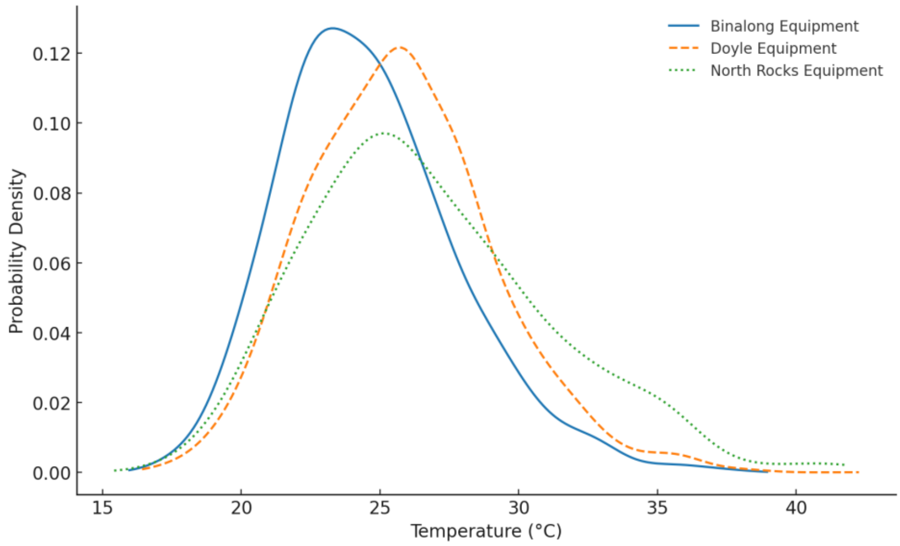


Figure 35. Counts by the equipment-facing sensors at Binalong Park, Doyle Ground and North Rocks Park as a function of the hourly mean local air temperature (measured by the temperature dataloggers on site). Here, the probability density is computed with a kernel density estimation, using a Gaussian, with a 0.5 °C width.

Separating the counts of sensors that face swings, we observe a similar pattern for Binalong Park and Doyle Ground, although with more counts for Doyle Ground in the high-temperature range. In contrast, data from North Rocks show irregular spikes (Figure 36). This is likely due to the low total counts (Figure 33c), which is consistent with the literature on the thermal dependency of visitation and use of public places, which has a random component[26]. If the total count is low, the random component prevails. The sensors facing the castle & slide, instead, display peaks of activity centred around different temperatures for Binalong Park (23.3 °C) and Doyle Ground (26.1 °C), with an intermediate value for North Rocks (25.5 °C) (Figure 37).

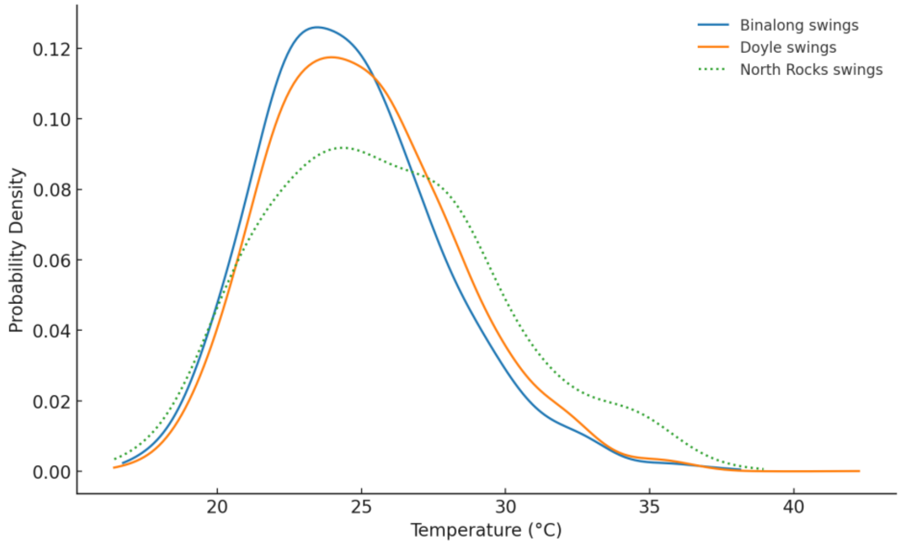


Figure 36. Counts by the swings-facing sensors at Binalong Park, Doyle Ground and North Rocks Park as a function of the hourly mean local air temperature (measured by the temperature dataloggers on site). Here, the probability density is computed with a kernel density estimation, using a Gaussian, with a 0.5 °C width.

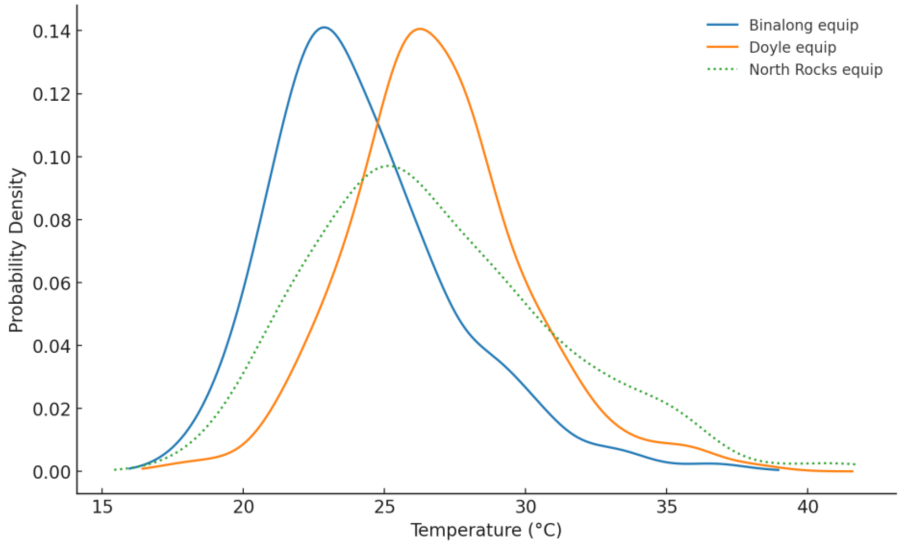


Figure 37. Counts by the equipment-facing sensors pointing at the castle & slide at Binalong Park, Doyle Ground and North Rocks Park as a function of the hourly mean local air temperature (measured by the temperature dataloggers on site). Here, the probability density is computed with a kernel density estimation, using a Gaussian, with a 0.5 °C width.

The observation reported in the literature[26] that casual (random) visitation may not follow a trend. Thus, it may have a stronger influence on observed patterns with low rather than absolute counts, as confirmed by the analysis of systematic trends and unsystematic residuals (Figures 38-40). For all playgrounds, the gate counts exhibit a low unexplained variance of less than 1%, with the largest unsystematic component observed for WR Musto, likely due to the proximity to a childcare centre, which induces casual visitation, and the overall small counts (Figure 38). Therefore, the correlation between visitation and local temperature is quite strong, with a significant systematic component.

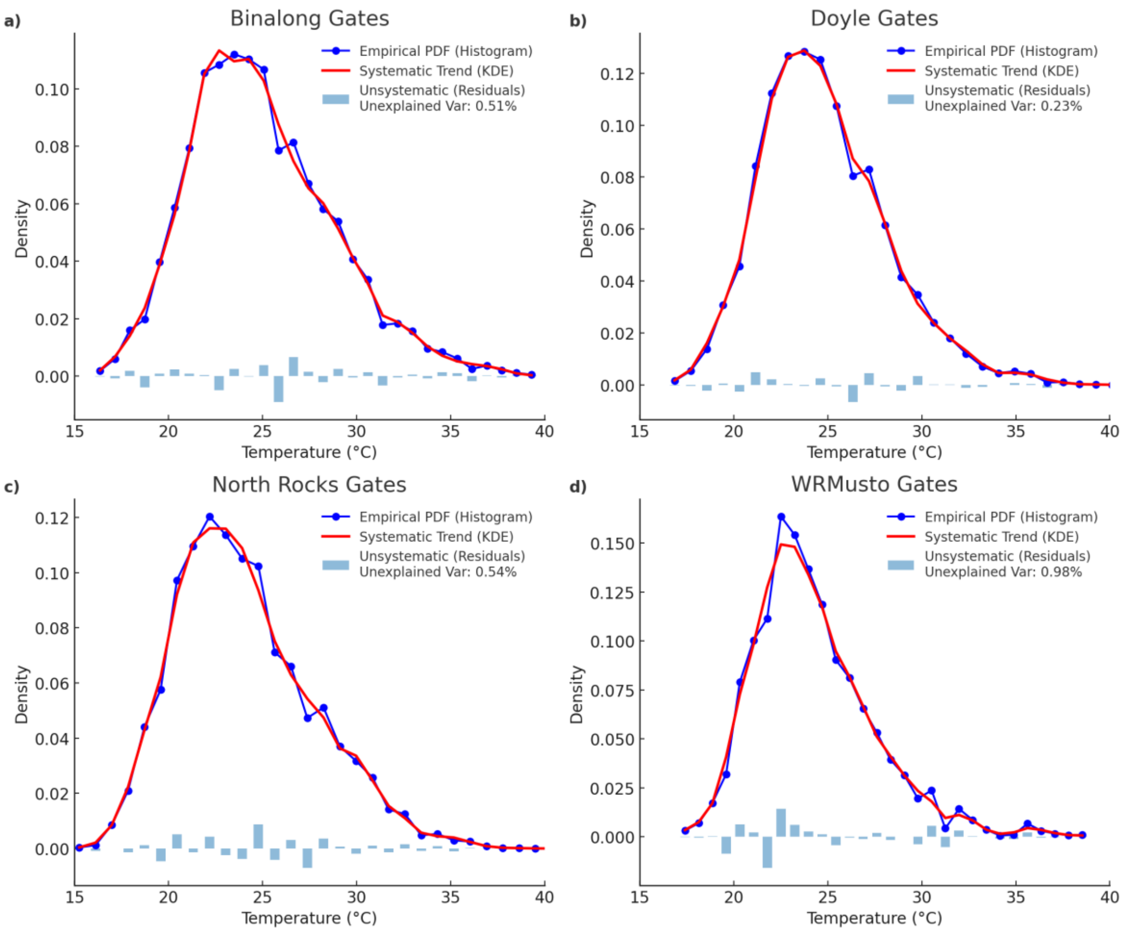


Figure 38. Probability density function for gate-facing counters decomposed into Empirical, systematic trend and unsystematic residuals. The unexplained variance refers to the unsystematic component of the total variance. Here, the empirical PDF is computed with temperature bins (histogram-based probability density).

The counts of the equipment-facing sensors, which represent the intensity of playground activity, also exhibit a small unsystematic variance for Binalong Park and Doyle Ground, of less than 1%. In contrast, it is nearly 5% at North Rocks, with some peak deviations in the intermediate temperature range (Figure 39). Therefore, it is worthwhile to investigate further the variance in activity levels for different types of equipment. By decomposing the data by equipment type, we observe that the unexplained variance is particularly strong at North Rocks, accounting for 19% of the total variance for the swings (Figure 40). The swings at Binalong Park and Doyle Ground, instead, show low unexplained variance, although with some spikes in the intermediate temperature range for the castle & slide equipment.

In addition to low counts and casual visitation, which may lead to unsystematic engagement with the playground equipment, other factors credited in the literature as contributing to unexplained variance include psychological and transient effects[43] and alliesthesia[iv]. In fact, people may *feel thermally pleasant if the environment can offset the thermal stress*[44], thus allowing them to engage in more intense activity.

[iv] From Parkinson and de Dear (2014)[51]: *thermal alliesthesia is a conceptual framework to understand the hedonics of a much larger spectrum of thermal environments than the more thoroughly researched concept of thermal neutrality. At its simplest, thermal alliesthesia states that the hedonic qualities of the thermal environment are determined as much by the general thermal state of the subject as by the environment itself.*

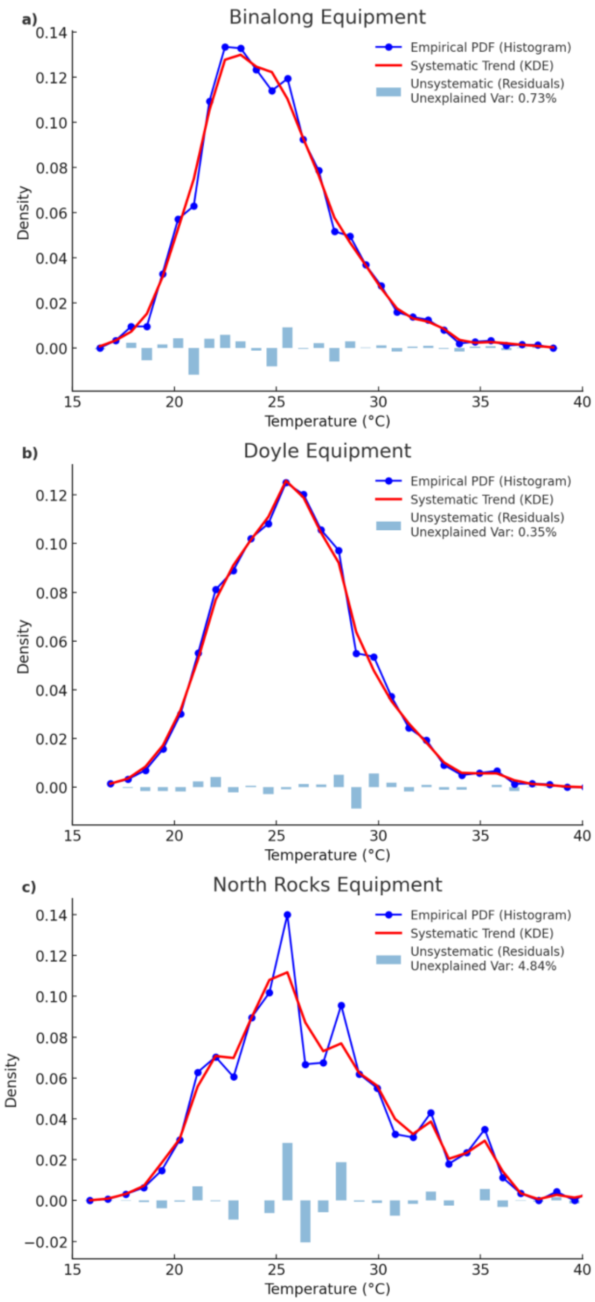


Figure 39. Probability density function for equipment-facing counters decomposed into Empirical, systematic trend and unsystematic residuals. The unexplained variance refers to the unsystematic component of the total variance. Here, the empirical PDF is computed with temperature bins (histogram-based probability density).

As discussed in precedence, the probability density function normalises data, and therefore, it is not possible to compare both shape and magnitude at the same time. Consequently, we can have a more holistic consideration of the trends and intensity of the activity by using a scaled probability density function (PDF), which is computed by multiplying the total count times the PDF, with the area under the curve representing the total counts (Figure 41). This way, we see that at Doyle Ground, activity is present both in terms of intensity and over a wide temperature range (Figure 41). Therefore, even if swings at North Rocks may be used in a wider temperature range, what really matters is whether they are also significantly used in a wide temperature range. Swings at Doyle Ground present a similar temperature range of use to Binalong Park, but with a higher intensity of use, likely also because they are sheltered from the sun by shade sails. The low activity at the castle & slide at Binalong Park compared with Doyle Ground (both in shaded conditions) cannot be fully explained by temperature. Thus, temperature alone is insufficient to fully describe the thermal performance of a playground, and local thermal comfort measurements are required.

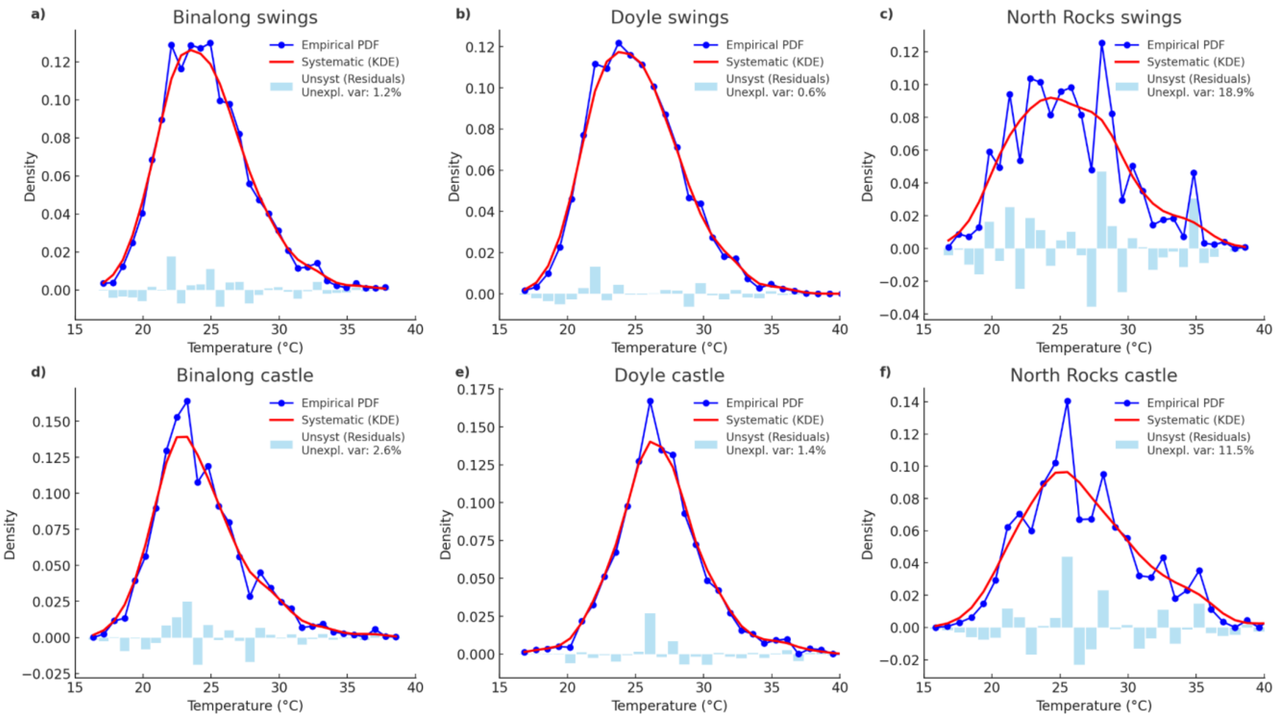


Figure 40. Probability density function for swing-facing and castle-facing counters decomposed into Empirical, systematic trend and unsystematic residuals. The unexplained variance refers to the unsystematic component of the total variance. Here, the empirical PDF is computed with temperature bins (histogram-based probability density).

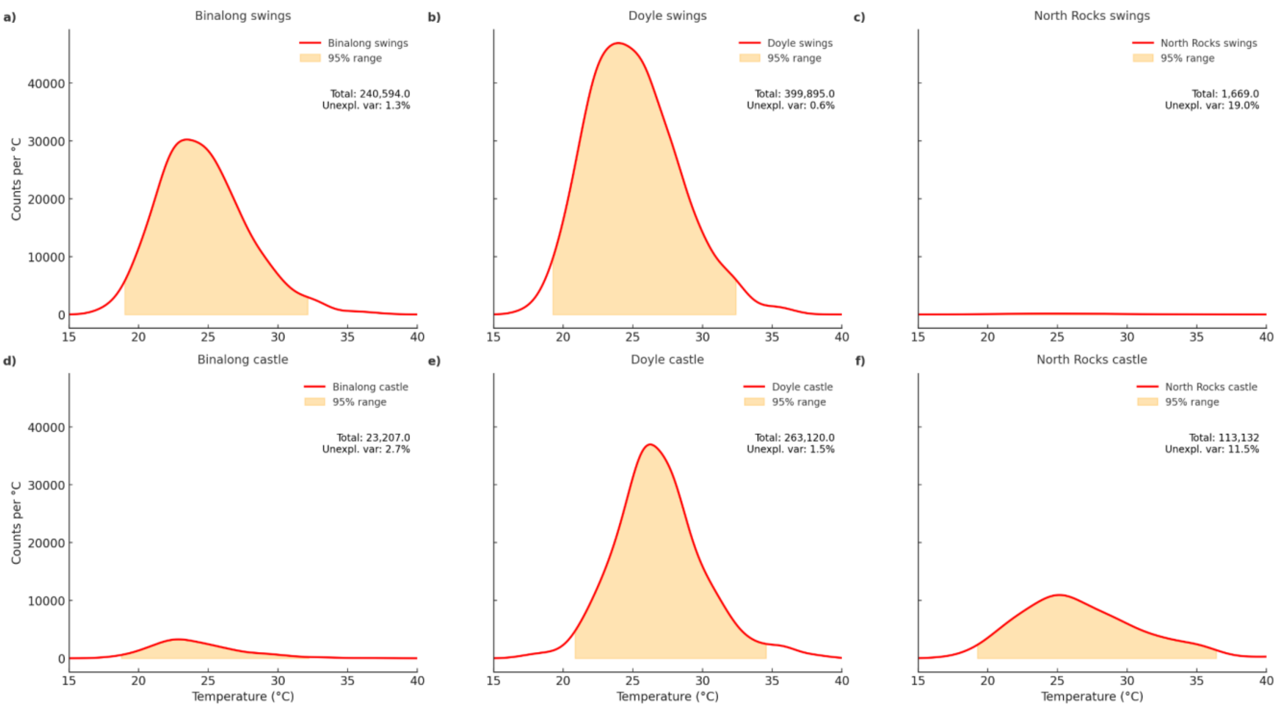


Figure 41. Counts weighted probability density function for swing-facing and castle-facing counters decomposed into Empirical, systematic trend and unsystematic residuals. The unexplained variance refers to the unsystematic component of the total variance. Here, the empirical PDF is computed with temperature bins (histogram-based probability density).

3.3 Albedo Measurements

Albedo measurements indicate that the majority of artificial surfaces have low albedos, and even light-coloured rubber exhibits high solar absorption, as seen in the “White” rubber at Binalong Park (Table 2). These low albedos are explained by the fact that soft-fall material has only superficial colouring of the granules, while sunlight penetrates, reaching the dark rubber, similarly to what happens with roofing felt and asphalt shingles[45,46]. The teal rubber at Doyle Ground is actually more reflective, with an albedo of 0.25-0.26, while the highest measured albedo is that of white concrete on a footpath at Doyle Ground (0.39). Thus, even non-black surfaces such as the soft-fall at North Rocks may present a very low albedo (0.06), which is comparable to a black paint. These are all typically low albedos that are common to playground surfaces[47].

Table 2. Measured albedo or solar reflectance (SR) by playground and surface. The calculation of the Solar Reflectance Index (SRI) is not applicable to grass and vegetated surfaces.

Playground	Target	Solar Reflectance (SR)	SRI
Binalong Park	"White" rubber	0.18	19
	Dark rubber under swings	0.06	4
	Blue patch	0.16	16
	Concrete with visible aggregate	0.16	16
	Grass	0.23	n/a
Doyle Ground	Mulch	0.17	17
	Teal rubber next to swings	0.25	29
	White concrete	0.39	46
	Teal rubber next to swings P2	0.26	28
	Dirt/mulch (next to timber equipment)	0.17	17
	Grass out of playground (sports field)	0.23	n/a
WR Musto	Artificial turf	0.21	22
	Dark rubber under swings	0.07	5
	Concrete near bench	0.15	15
	Patched old rubber next to castle	0.10	9
North Rocks Park	Green rubber	0.06	3
	Concrete	0.19	20
	Grass	0.24	n/a

3.4 Field Campaigns

3.4.1 Surface temperatures

Surface temperatures are plotted against the incoming solar radiation measured by the reference weather station that we positioned over grass in an open area immediately near the playground.

Here, in addition to the absolute value of the surface temperature of each material, we use the difference between the surface temperature of different materials at playgrounds and the local ambient temperature (measured from the reference station at 1.5 m above the grass, immediately adjacent to the playgrounds). This approach enables comparison between different surfaces and materials measured on distinct clear-sky days, when the base air temperature may vary (some uncertainty may arise from small differences in wind speed). This temperature difference also quantifies how much a surface overheats above its ambient temperature due to its optical-radiative properties, thermal conductivity, and other factors. This approach is commonly used to define the performance of daytime radiative coolers[48] and has already been used for playgrounds[10]. In fact, if a surface is at a temperature above ambient, it heats the built environment by convection (positive turbulent sensible heat flux from the surface), whereas if it is near ambient temperature, it does not worsen the local microclimate.

The highest surface temperatures are measured at Binalong Park Playground, as on the day of the field campaign, it reached extreme heat conditions with peak air temperatures even exceeding 42 °C. More in detail, the surface temperature of dark soft-fall (with solar reflectance equal to 0.06) exceeded 85 °C for several hours (Figure 42), or more than 45 °C above the ambient temperature (Figure 43).

The only sunlit surface at a near-ambient temperature was grass, thanks to evapotranspiration and the overall physiology of vegetated surfaces, which can retain a low temperature in the sun even if they present an intermediate-low albedo (Figure 43).

The wood of the benches also reached high surface temperatures, exceeding 30 °C above ambient air. Some surfaces displayed an intermediate increase in surface temperatures as they had been partially shaded for a period of time before the measurements. Also, hard surfaces with high thermal mass, such as asphalt (aged) and concrete, were at 15-20 °C above ambient temperature and cooler than soft-fall with similar reflectance, thanks to the thermal energy storage provided by the dense materials with high thermal conductivity and heat capacity, thus producing a time shift in surface temperature[49].

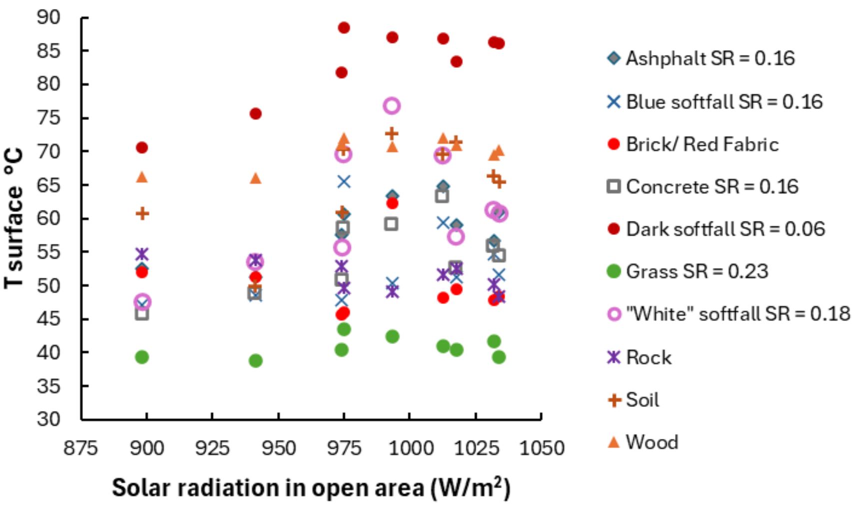


Figure 42. Surface temperature of the different materials as a function of incoming solar radiation measured at Binalong Park on 28/01/2025.

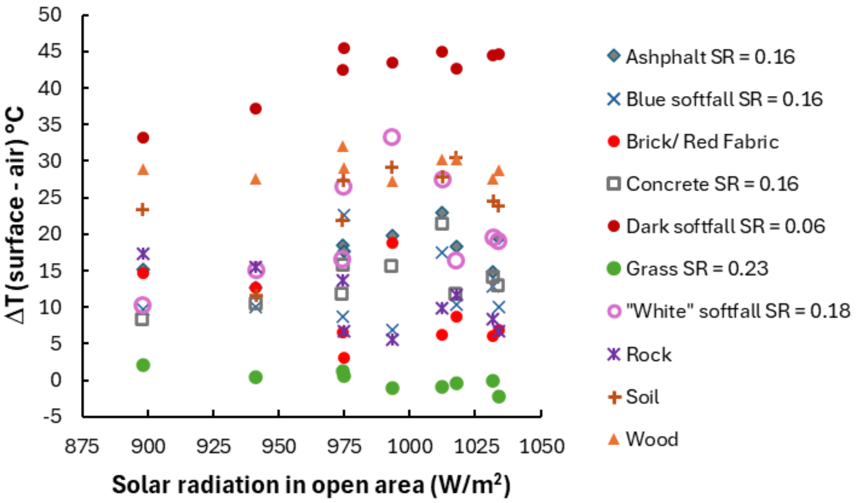


Figure 43. Difference between the surface temperature of the different materials and the ambient temperature (measured at 1.5 m over grass) as a function of incoming solar radiation measured at Binalong Park on 28/01/2025.

Surface temperatures at Doyle Ground Playground (Figures 44-45) and North Rocks Park Playground (Figures 46-47) are lower than those at Binalong Park, as the ambient temperature was lower during the campaigns, reaching 32 °C. However, the incoming solar and infrared radiation, sky conditions (clear) and wind speed were comparable. The only exception is the dark green soft-fall at North Rocks Park (solar reflectance = 0.06), which reached 85 °C, and thus was 54 °C above ambient air temperature (Figures 46-47). In comparison, the maximum increase above ambient temperature observed at any playground for any other surface is 45 °C.

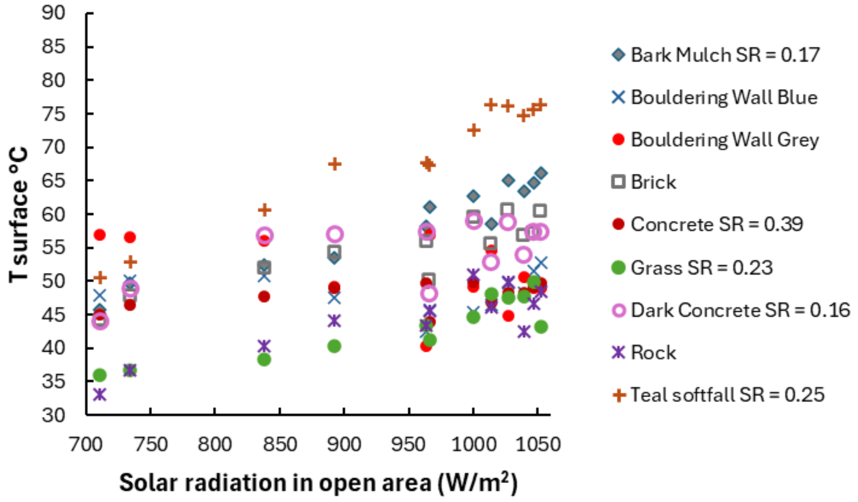


Figure 44. Surface temperature of the different materials as a function of incoming solar radiation measured at Doyle Ground Playground on 16/12/2024.

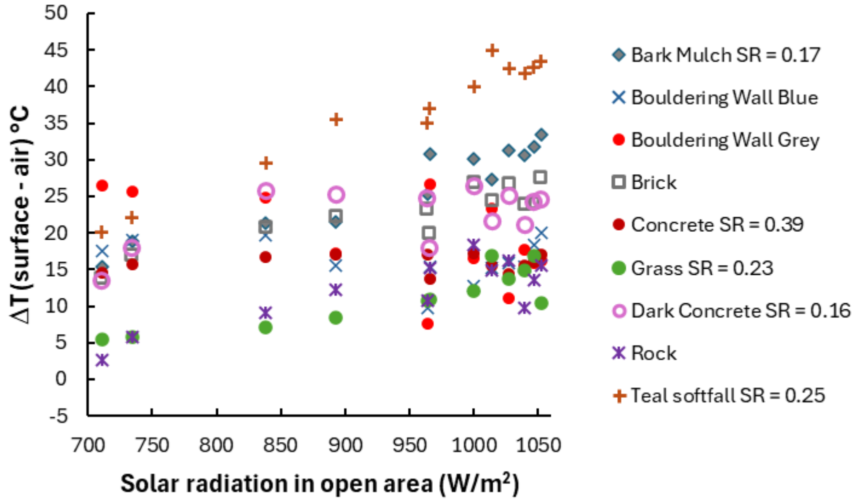


Figure 45. Difference between the surface temperature of the different materials and the ambient temperature (measured at 1.5 m over grass) as a function of incoming solar radiation measured at Doyle Ground Playground on 16/12/2024.

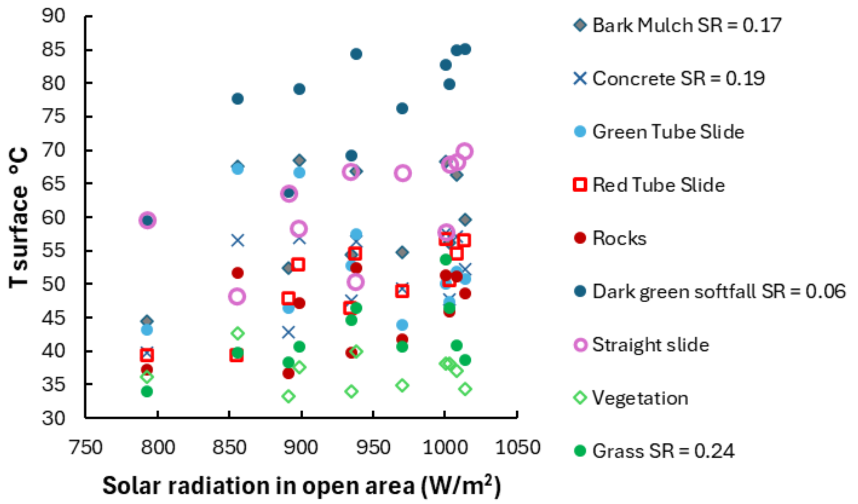


Figure 46. Surface temperature of the different materials as a function of incoming solar radiation measured at North Rocks Park Playground on 07/02/2025.

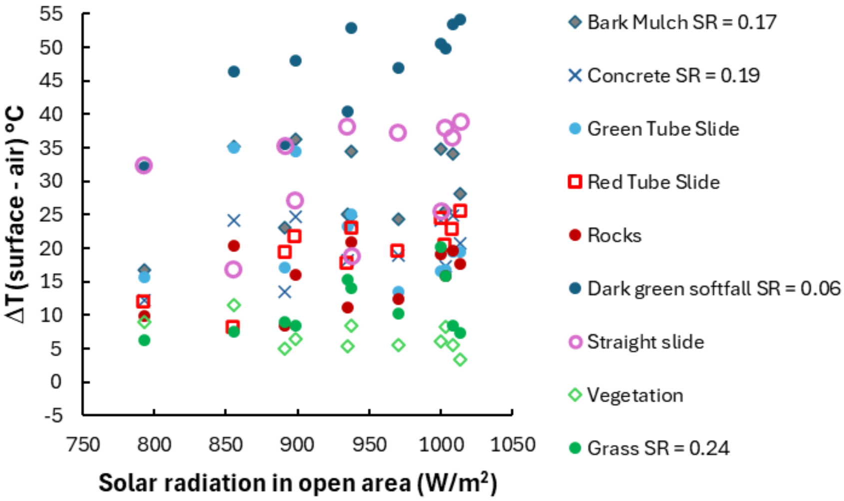


Figure 47. Difference between the surface temperature of the different materials and the ambient temperature (measured at 1.5 m over grass) as a function of incoming solar radiation measured at North Rocks Park Playground on 07/02/2025.

The measured surface temperatures at the three playgrounds confirmed observations made at playgrounds across Western Sydney[1,24] and overseas[10,47]. The playground flooring is designed to mitigate the impact of falls, but generally reaches high surface temperatures under the sun, often exceeding 75 °C, due to its high solar absorbance. Uncovered soil or bark also exhibits high surface temperatures, largely exceeding 60 °C, while grass retains a low surface temperature close to the ambient temperature.

3.4.2 UV Radiation Exposure

The field campaigns were done at the three playgrounds on three different sunny and hot days: on 16 December 2024 at Doyle Ground Playground (Tmax: 32.3 °C), on 28 January 2025 at Binalong Park Playground (Tmax: 42.8 °C) and on 7 February 2025 at North Rocks Playground (Tmax: 32.2 °C). WR Musto was not included after the pilot due to the low visitation count and the planned renovation (the results of the pilot are presented in Annex B). At each playground, a reference station was positioned 1.5 m above the grass, measuring air temperature and humidity, wind speed, and incoming solar, infrared, and ultraviolet radiation. Seven rounds of measurements were collected at the different measurement spots identified in Section 2.3 (Figures 16-19), which encompass shaded and unshaded positions over different materials.

As each round took approximately 25-30 minutes, the incoming solar radiation, air temperature and wind speed at the beginning of the round were sometimes slightly different from those at the end of the round. Therefore, we normalised the data using the data from the reference station. The plots without normalisation are provided in Annex A.

Here, we considered the local UV index measured at different shaded and unshaded locations (Figures 48-50). Our local measurements in an open area were in line with the UV index measured by ARPANSA at the Miranda site in Sydney (Annex A), although we note that the distance between the ARPANSA site and our measurement area implies that even in a perfectly clear sky day, small differences in sky conditions due to haziness or high-level humidity are possible. The thresholds on the charts are those defined by the World Health Organization for ultraviolet radiation exposure, with sun protection recommended when the UV index is 3 or above (i.e., slip, slop, slap, seek, and slide).

On the days of the campaigns at Binalong Park and Doyle Ground the UV index exceeded 11 (or extreme) and many play areas at the playgrounds presented very high (8-10) or extreme (≥ 11) UV index for most of the day, such as the swings at Binalong Park (Position 1, unshaded) or the climb boulder at Doyle Ground (Point 5, unshaded). At Binalong Park, even below the canopy, the UV index was above 5 (between moderate and high), thus requiring personal sun protection.

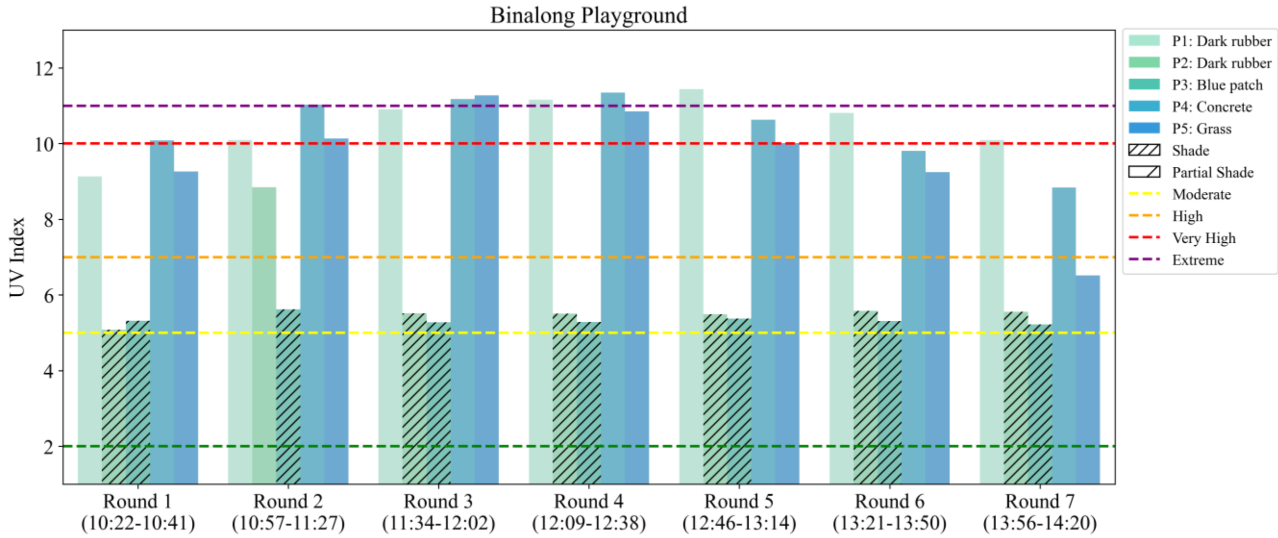


Figure 48. UV index at Binalong Park Playground at different locations (as in Figure 16) and at different time intervals.

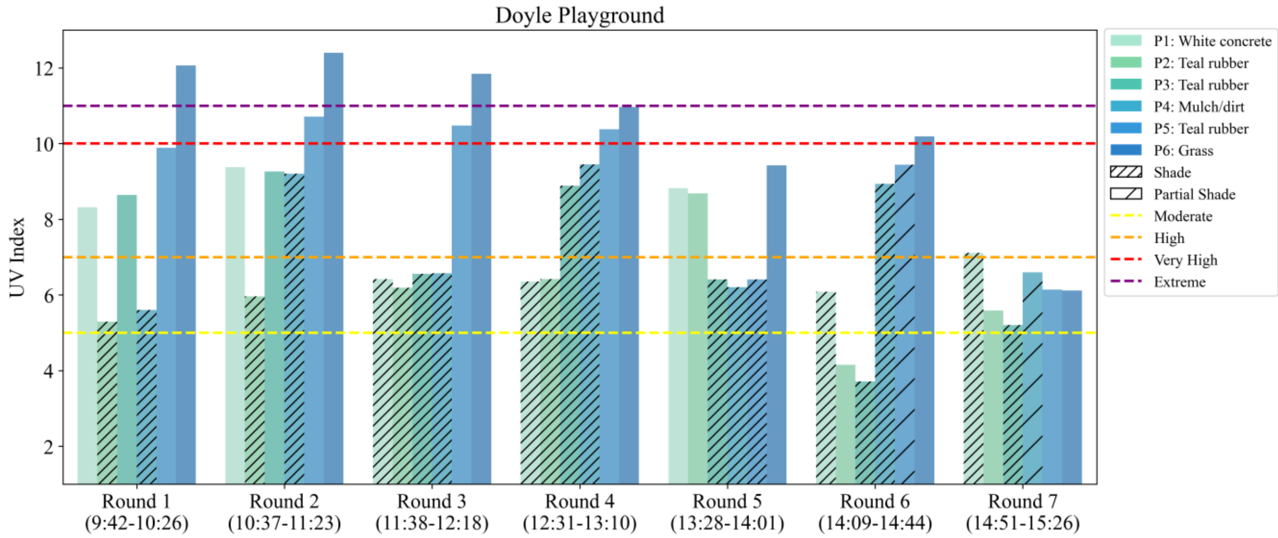


Figure 49. UV index at Doyle Ground Playground at different locations (as in Figure 17) and at different time intervals.

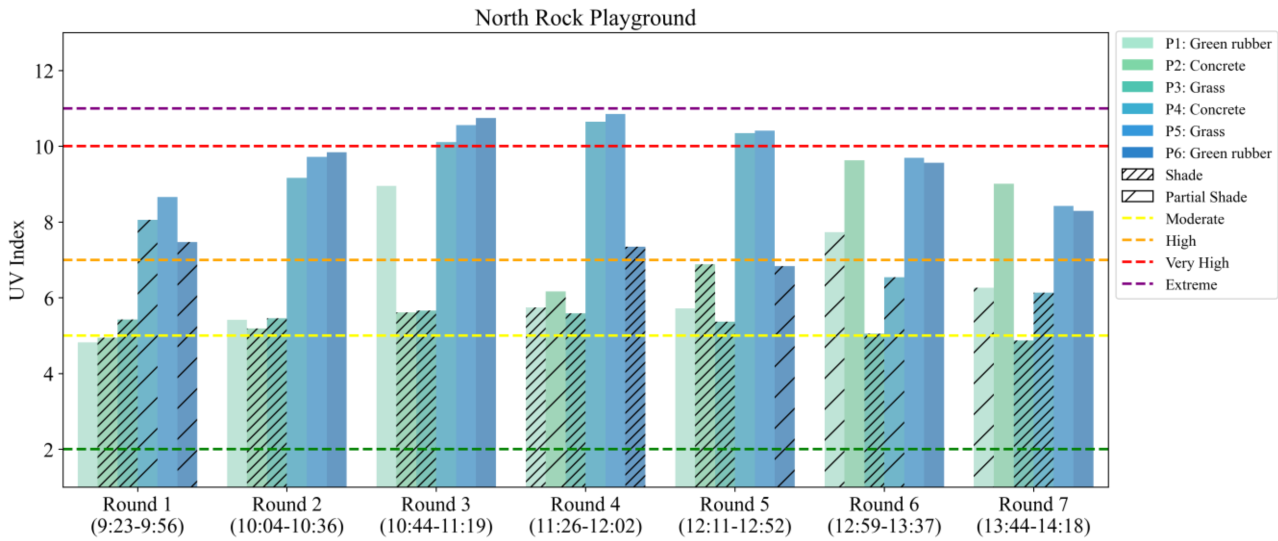


Figure 50. UV index at North Rocks Park Playground at different locations (as in Figure 19) and at different time intervals.

At North Rocks Park, instead, the position of the trees provided some intermediate shade to the castle & slide equipment, as well as the footpath (Positions 1 and 2, respectively, Figure 50). These were occasionally exposed to high UV index in the morning and then consistently in the afternoon.

Among the three playgrounds, the canopy at Binalong Park is the most effective in reducing both the ultraviolet and the total solar radiation during the central hours of the day. However, even the limited natural shade available at North Rocks Park is helpful in the morning, shading the main equipment on site and limiting the UV index to levels similar to those under shade at Binalong Park, while the rest of the equipment on site (climb structure and swings) remains unshaded.

Drone-captured images of the playgrounds (Figures 51-52) show how Binalong Park is provided with better shade and coverage, even if Doyle Ground benefits from a good combination of natural and artificial shade.

The images also demonstrate how the canopies are partially transparent, and the equipment can be seen through. This explains why even in the centre under the shade sail fabric, the ultraviolet radiation is still 20-25% of that measured in full sun. While ultraviolet radiation has a greater diffuse fraction than visible and near-infrared radiation, this quantity cannot be entirely ascribed to the diffuse component. As noted by Parisi et al. (2000), *the high diffuse UV component in the shade may result in high UV exposures not only to unprotected parts of the body on a horizontal plane, but also in equally high UV irradiances to parts of the body, including the eyes and face, that are not UV protected*[23].

Figure 51. A drone captured image of the shades at Binalong Park.

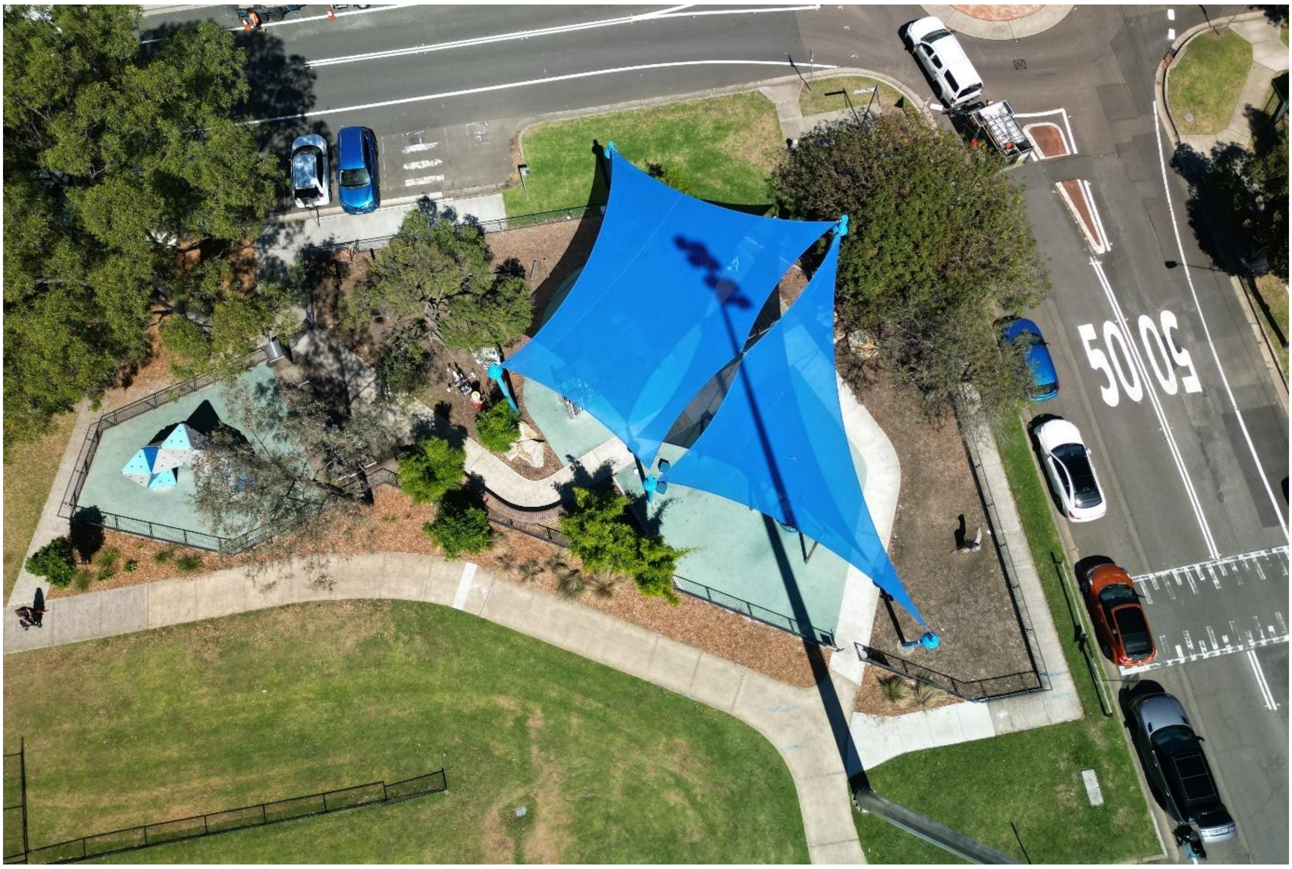


Figure 52. A drone captured image of the shade sails at Doyle Ground.

3.4.3 Thermal Environment and Outdoor Thermal Comfort

The thermal comfort at the three sites was evaluated using the Universal Thermal Climate Index (UTCI)[50], which provides a "feels-like" temperature and takes into account not only the exposure to temperature and humidity but also the solar and infrared radiation reaching the human body. UTCI is currently considered the most advanced thermal comfort metric for outdoor environments across the scientific community. At Binalong Park, the UTCI exceeded extreme heat stress conditions at all unshaded positions, while it was everywhere above the strong heat stress threshold, due to the very hot day, with a peak air temperature exceeding 42 °C (Figure 53). During the central hours of the day, the UTCI was approximately 41 °C in shaded positions (under artificial shade, positions 2 and 3) and exceeded 49 °C at unshaded locations, which was 8 °C higher than under shade. This occurred even above the grass, due to the strong incoming solar and thermal radiation.

At Doyle Ground, a similar pattern was observed, with the UTCI at unshaded locations more than 6 °C higher than at shaded positions (Figure 54). Extreme heat stress conditions were also observed at Doyle Ground, even though the maximum air temperature reached 32.2 °C, which is 10 °C lower than during the campaign at Binalong Park. At neither Binalong Park nor Doyle Ground was the artificial shade sufficient to keep conditions below strong heat stress levels (i.e., UTCI ≥ 32 °C).

At North Rocks Park, significant differences in UTCI were observed between unshaded and shaded locations, with UTCI differences occasionally reaching 12 °C (Figure 55). This can be attributed to the natural shade provided by trees and other vegetation on the north side of the site, which protected it from solar radiation incident on both horizontal and vertical planes and limited the amount of thermal radiation coming from the side (Figure 55).

Overall, we can observe helpful features to improve thermal comfort at all three sites. The best artificial shade is found at Binalong Park, with the optimal combination of artificial and natural shade at Doyle Ground, and the helpful positioning of trees and other vegetation at North Rocks Park. No playground presents all these features combined.

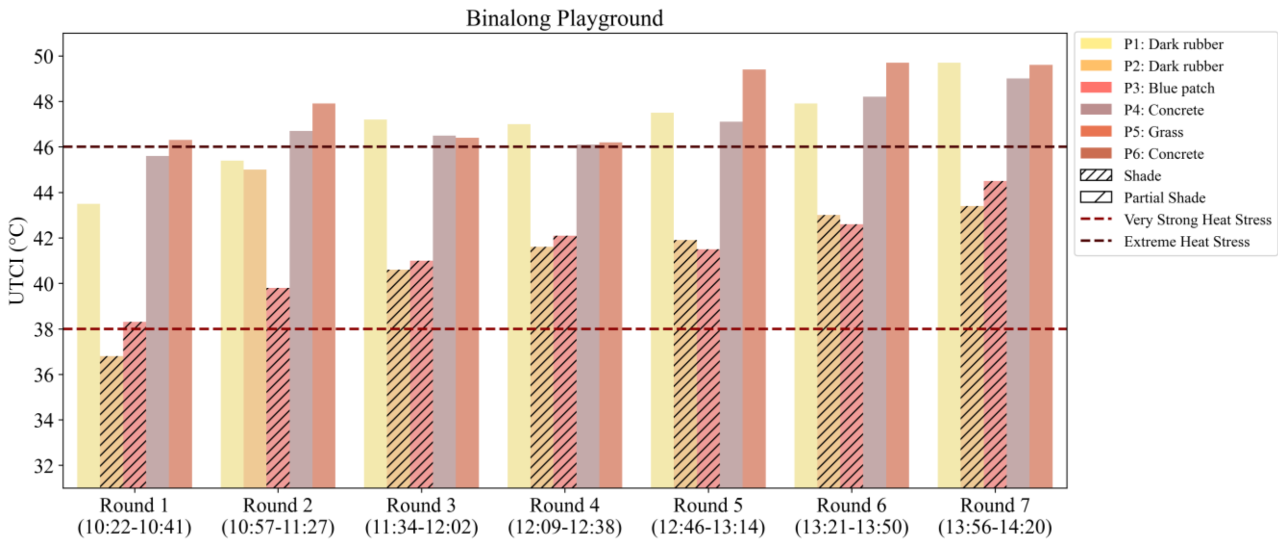


Figure 53. Universal Thermal Climate Index describing the local thermal comfort conditions at Binalong Park Playground at different locations (as in Figure 16) and at different time intervals.

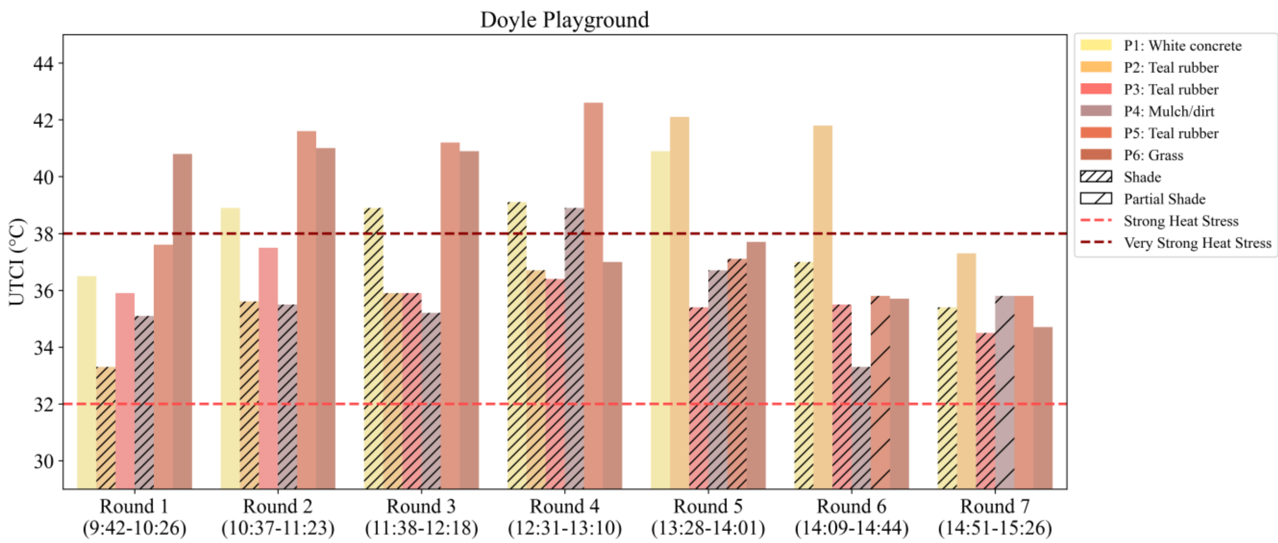


Figure 54. Universal Thermal Climate Index describing the local thermal comfort conditions at Doyle Ground Playground at different locations (as in Figure 17) and at different time intervals.

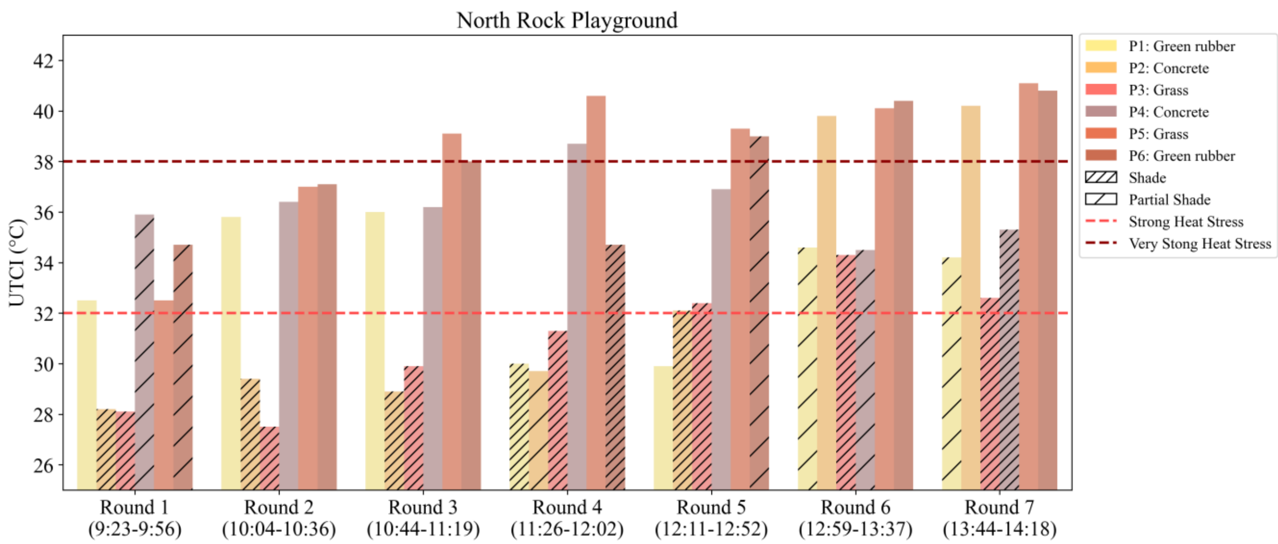


Figure 55. Universal Thermal Climate Index describing the local thermal comfort conditions at North Rocks Park Playground at different locations (as in Figure 19) and at different time intervals.

4. Conclusions

In this project, we investigated the thermal conditions, UV exposure, and visitation patterns across four representative playgrounds in Parramatta (Binalong Park, Doyle Ground, WR Musto and North Rocks Park). Through a combination of long-term monitoring, short-term field campaigns, and biometeorology measurements, the project has generated robust evidence of the thermal challenges faced by public playgrounds and their impact on usability. Key findings demonstrate that:

- Thermal conditions at playgrounds regularly exceed safe thresholds, with surface temperatures reaching up to 85 °C and UTCI values indicating extreme heat stress, particularly in unshaded areas.
- UV radiation exposure remains high even under partial shade, with UV indices frequently exceeding WHO thresholds for sun protection, underscoring the need for comprehensive shading solutions.
- Playground visitation and activity are strongly correlated with local temperature, with shaded equipment supporting longer and more intense use, especially during warmer periods. However, activity declines sharply above 30 °C, suggesting a clear thermal threshold for playability.
- Material choices significantly influence surface temperatures, with low-albedo synthetic surfaces contributing to overheating. Natural surfaces such as grass consistently retain lower temperatures under the sun.
- Local microclimate variations exist but do not fully account for differences in playground use, reinforcing the importance of design features—particularly shade quality and equipment layout—in shaping thermal comfort and playability.

The findings confirm the crucial role of climate-sensitive design in ensuring equitable access to outdoor play. They also highlight the value of integrating environmental monitoring into playground planning and renovation processes. While this study does not directly address sociological or health outcomes, it provides a strong empirical foundation for future interdisciplinary research and policy development.

In conclusion, enhancing shade provision, selecting thermally appropriate materials, and incorporating bioclimatic design principles are essential strategies to ensure that playgrounds remain safe, inclusive, and usable under a warming climate. The insights from this project offer actionable guidance for local governments, designers, and community stakeholders committed to improving urban play environments.

5. References

1. Pfautsch, S., Wujeska-Klause, A. & Walters, J. Outdoor playgrounds and climate change: Importance of surface materials and shade to extend play time and prevent burn injuries. *Build Environ* **223**, 109500 (2022).
2. Benchmarking shade in NSW playgrounds | Cancer Institute NSW. https://www.cancer.nsw.gov.au/prevention-and-screening/preventing-cancer/preventing-skin-cancer/shade-and-uv-protection/benchmarking-shade-in-nsw-playgrounds.
3. Tremblay, M. S. *et al.* Position Statement on Active Outdoor Play. *International Journal of Environmental Research and Public Health 2015, Vol. 12, Pages 6475-6505* **12**, 6475–6505 (2015).
4. United Nations. *Convention on the Rights of the Child*. https://www.ohchr.org/en/instruments-mechanisms/instruments/convention-rights-child (1989).
5. Latham, A. & Layton, J. Social infrastructure and the public life of cities: Studying urban sociality and public spaces. *Geogr Compass* **13**, e12444 (2019).
6. Garshasbi, S. *et al.* Urban mitigation and building adaptation to minimize the future cooling energy needs. *Solar Energy* **204**, 708–719 (2020).
7. Santamouris, M. *et al.* Heat mitigation technologies can improve sustainability in cities. An holistic experimental and numerical impact assessment of urban overheating and related heat mitigation strategies on energy consumption, indoor comfort, vulnerability and heat-related m. *Energy Build* **217**, 110002 (2020).
8. Nazarian, N. *et al.* Integrated Assessment of Urban Overheating Impacts on Human Life. *Earths Future* **10**, e2022EF002682 (2022).
9. Vanos, J. K. Children’s health and vulnerability in outdoor microclimates: A comprehensive review. *Environ Int* **76**, 1–15 (2015).
10. Lehnert, M. *et al.* Overheated children’s playgrounds in Central European cities: The effects of surfaces and shading on thermal exposure during hot summer days. *Urban Clim* **55**, 101873 (2024).
11. Strong, D., Tahir, A. & Verma, S. Not fun in the sun: playground safety in a heatwave. *Emergency Medicine Journal* **24**, e9–e9 (2007).
12. Liu, S. *et al.* Dynamic thermal pleasure in outdoor environments - temporal alliesthesia. *Science of The Total Environment* **771**, 144910 (2021).
13. Nazarian, N. & Lee, J. K. W. Personal assessment of urban heat exposure: a systematic review. *Environmental Research Letters* **16**, 033005 (2021).
14. Walters, J. R. & Pfautsch, S. The heat-safe play index (H-SPI): A tool to compare relative thermal safety of outdoor playgrounds. *Urban For Urban Green* **106**, 128747 (2025).
15. Gefeller, O. & Diehl, K. Children and Ultraviolet Radiation. *Children 2022, Vol. 9, Page 537* **9**, 537 (2022).
16. ISO. ISO 13732-1 - Ergonomics of the thermal environment - methods for the assessment of human responses to contact with surfaces, in Part 1: Hot surfaces. Preprint at https://www.iso.org/standard/43558.html (2006).
17. Ebi, K. L. *et al.* Hot weather and heat extremes: health risks. *The Lancet* **398**, 698–708 (2021).
18. Zhang, L. *et al.* Outdoor Thermal Comfort of Urban Park—A Case Study. *Sustainability 2020, Vol. 12, Page 1961* **12**, 1961 (2020).

19. Madden, AL, Arora, V, Holmes, K, Pfautsch, S. *Cool Schools*. https://doi.org/10.26183/5b91d72db0cb7 (2018) doi:10.26183/5b91d72db0cb7.

20. Kaluarachichi, T. U. N., Tjoelker, M. G. & Pfautsch, S. Temperature Reduction in Urban Surface Materials through Tree Shading Depends on Surface Type Not Tree Species. *Forests 2020, Vol. 11, Page 1141* **11**, 1141 (2020).

21. Rajagopalan, P., Andamon, M. M., Paolini, R. & Santamouris, M. Developing experimental protocol for collecting large scale urban microclimate data through community participation. *Engaging Architectural Science: Meeting the Challenges of Higher Density: 52nd International Conference of the Architectural Science Association 2018* 561–568 (2018).

22. Ulpiani, G., Hart, M. A., Virgilio, G. di & Maharaj, A. M. Urban meteorology and air quality in a rapidly growing city: inter-parameter associations and intra-urban heterogeneity. *Sustain Cities Soc* 103553 (2021) doi:10.1016/J.SCS.2021.103553.

23. Parisi, A. V., Kimlin, M. G., Wong, J. C. F. & Wilson, M. Diffuse component of solar ultraviolet radiation in tree shade. *J Photochem Photobiol B* **54**, 116–120 (2000).

24. Pfautsch, S. & Wujeska-Klause, A. Guide to Climate-Smart Playgrounds: Research Findings and Application. (2021) doi:10.26183/2BGZ-D714.

25. Ciucci, E. *et al.* Weather daily variation in winter and its effect on behavior and affective states in day-care children. *Int J Biometeorol* **55**, 327–337 (2011).

26. Huang, J., Zhou, C., Zhuo, Y., Xu, L. & Jiang, Y. Outdoor thermal environments and activities in open space: An experiment study in humid subtropical climates. *Build Environ* **103**, 238–249 (2016).

27. Han, S. *et al.* Behaviour in public open spaces: A systematic review of studies with quantitative research methods. *Build Environ* **223**, 109444 (2022).

28. Estévez, J., Gavilán, P. & Giráldez, J. V. Guidelines on validation procedures for meteorological data from automatic weather stations. *J Hydrol (Amst)* **402**, 144–154 (2011).

29. Paolini, R. *et al.* The hygrothermal performance of residential buildings at urban and rural sites: Sensible and latent energy loads and indoor environmental conditions. *Energy Build* **152**, 792–803 (2017).

30. Curci, S. *et al.* Assessing measurement uncertainty in meteorology in urban environments. *Meas Sci Technol* **28**, (2017).

31. Thorsson, S., Lindberg, F., Eliasson, I. & Holmer, B. Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology* **27**, 1983–1993 (2007).

32. ASTM. ASTM E 1918: Standard test method for measuring solar reflectance of horizontal and low-sloped surfaces in the field. Preprint at (2016).

33. Akbari, H., Levinson, R. & Stern, S. Procedure for measuring the solar reflectance of flat or curved roofing assemblies. *Solar Energy* **82**, 648–655 (2008).

34. ASTM International. ASTM E 903-12. Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres. Preprint at https://doi.org/10.1520/E0903-12 (2012).

35. ASTM International. ASTM E 1980. Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low- Sloped Opaque Surfaces. Preprint at (2011).

36. ASTM. ASTM C 1371: Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers. Preprint at (2015).

37. CEN. EN 12898. Glass in building. Determination of the emissivity. Preprint at (2001).

38. CEN. EN 15976. Flexible sheets for waterproofing. Determination of emissivity. Preprint at (2011).

39. Khan, H. S., Paolini, R., Santamouris, M. & Caccetta, P. Exploring the Synergies between Urban Overheating and Heatwaves (HWs) in Western Sydney. *Energies (Basel)* **13**, 470 (2020).

40. Khan, H. S. *et al.* Spatiotemporal variation in urban overheating magnitude and its association with synoptic air-masses in a coastal city. *Sci Rep* **11**, 6762 (2021).

41. Khan, H. S., Santamouris, M., Paolini, R., Caccetta, P. & Kassomenos, P. Analyzing the local and climatic conditions affecting the urban overheating magnitude during the Heatwaves (HWs) in a coastal city: A case study of the greater Sydney region. *Science of the Total Environment* **755**, 142515 (2021).

42. Barry, R. & Chorley, R. *Atmosphere, Weather, and Climate*. (Methuen, London, UK, 1987).

43. Eliasson, I., Knez, I., Westerberg, U., Thorsson, S. & Lindberg, F. Climate and behaviour in a Nordic city. *Landsc Urban Plan* **82**, 72–84 (2007).

44. Liu, S. *et al.* Dynamic thermal pleasure in outdoor environments - temporal alliesthesia. *Science of The Total Environment* **771**, 144910 (2021).

45. Berdahl, P., Akbari, H., Jacobs, J. & Klink, F. Surface roughness effects on the solar reflectance of cool asphalt shingles. *Solar Energy Materials and Solar Cells* **92**, 482–489 (2008).

46. Paolini, R., Zinzi, M., Poli, T., Carnielo, E. & Mainini, A. G. Effect of ageing on solar spectral reflectance of roofing membranes: natural exposure in Roma and Milano and the impact on the energy needs of commercial buildings. *Energy Build* **84**, 333–343 (2014).

47. Vanos, J. K., Middel, A., McKercher, G. R., Kuras, E. R. & Ruddell, B. L. Hot playgrounds and children's health: A multiscale analysis of surface temperatures in Arizona, USA. *Landsc Urban Plan* **146**, 29–42 (2016).

48. Sui, C. & Hsu, P. C. Standardizing the Thermodynamic Definition of Daytime Subambient Radiative Cooling. *ACS Energy Lett* **9**, 2997–3000 (2024).

49. Tsoka, S., Theodosiou, T., Tsikaloudaki, K. & Flourentzou, F. Modeling the performance of cool pavements and the effect of their aging on outdoor surface and air temperatures. *Sustain Cities Soc* **42**, 276–288 (2018).

50. Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H. & Tinz, B. Comparison of UTCI to selected thermal indices. *Int J Biometeorol* **56**, 515–535 (2012).

51. Parkinson, T. & De Dear, R. Thermal pleasure in built environments: Physiology of alliesthesia. *Building Research and Information* **43**, 288–301 (2015).

Annex A – UV-index and thermal comfort measurements before data normalisation

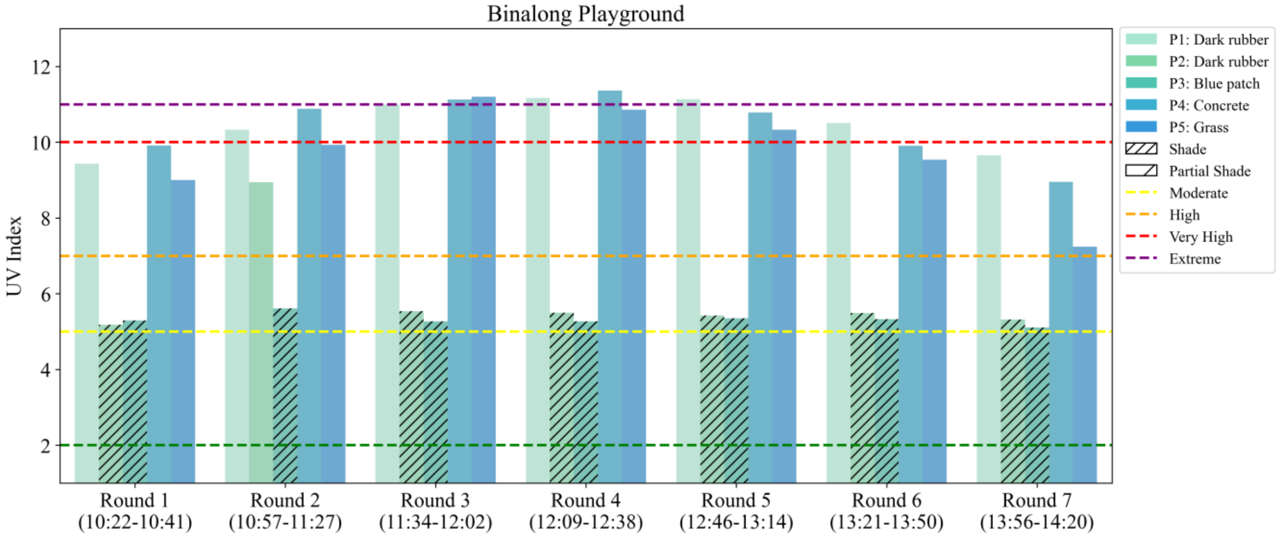


Figure S1. UV index at Binalong Park Playground at different locations (as in Figure 16) and at different time intervals.

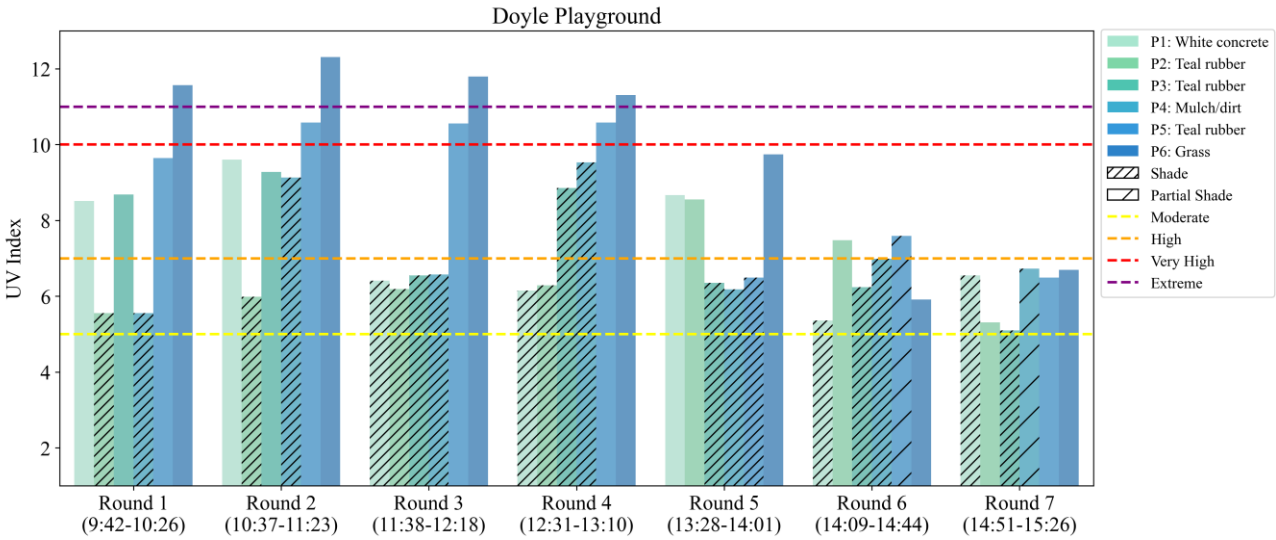


Figure S2. UV index at Doyle Ground Playground at different locations (as in Figure 17) and at different time intervals.

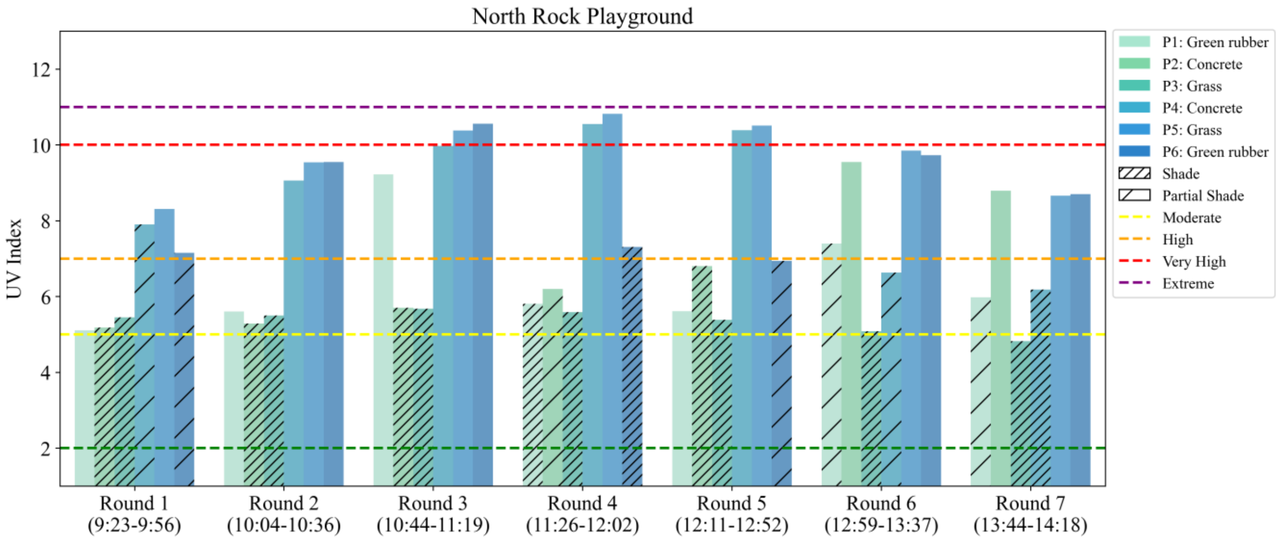


Figure S3. UV index at North Rocks Park Playground at different locations (as in Figure 19) and at different time intervals.

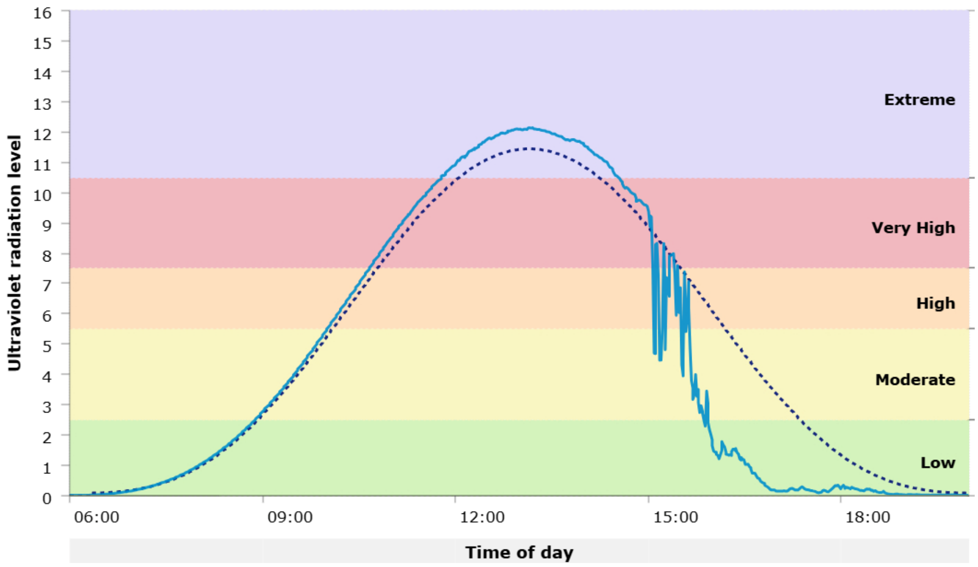


Figure S4. Binalong Park campaign. UV index measured by ARPANSA (solid line) and theoretical (dashed line) on 28/01/2025.

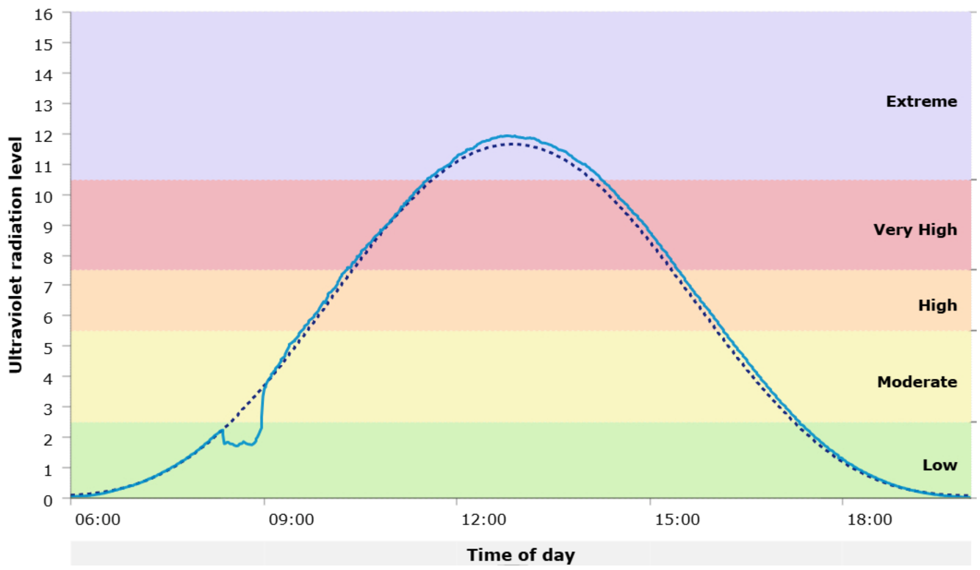


Figure S5. Doyle Ground campaign. UV index measured by ARPANSA (solid line) and theoretical (dashed line) on 16/12/2024.

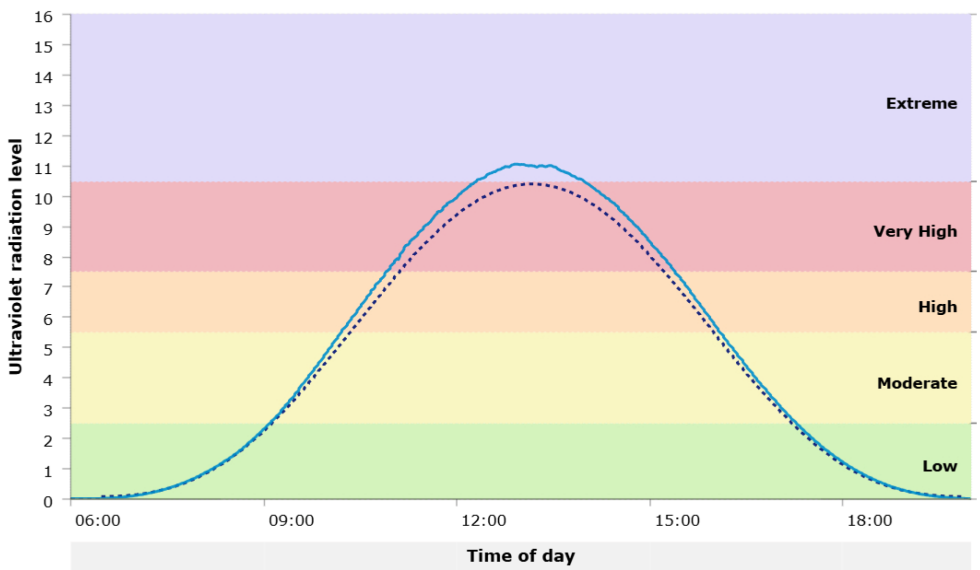


Figure S6. North Rocks campaign. UV index measured by ARPANSA (solid line) and theoretical (dashed line) on 07/02/2025.

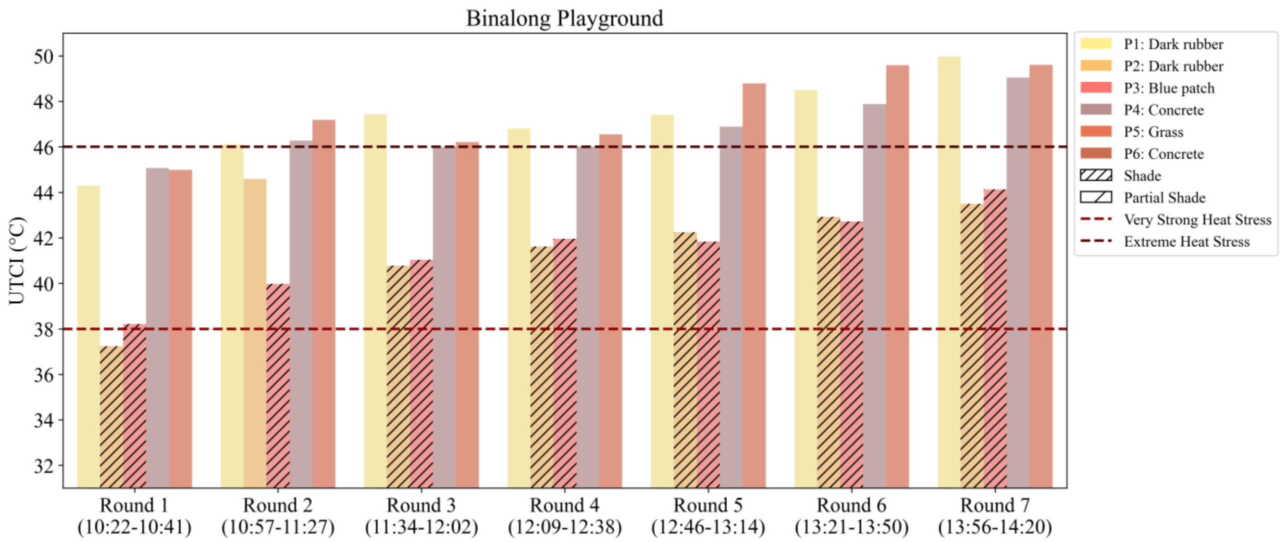


Figure S7. Universal Thermal Climate Index describing the local thermal comfort conditions at Binalong Park Playground at different locations (as in Figure 16) and at different time intervals.

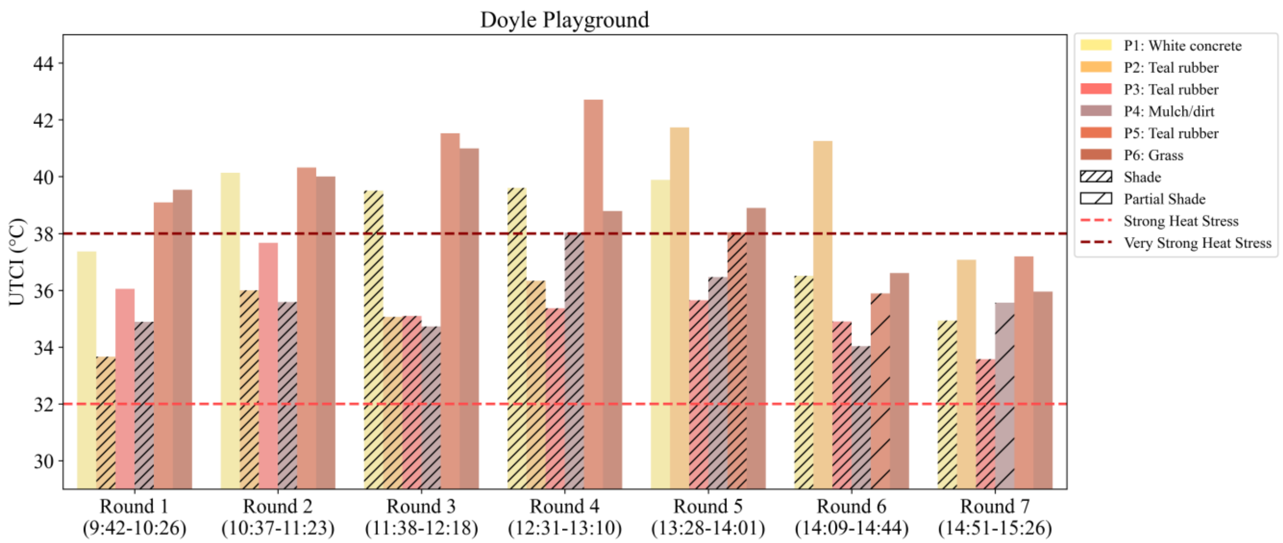


Figure S8. Universal Thermal Climate Index describing the local thermal comfort conditions at Doyle Ground Playground at different locations (as in Figure 17) and at different time intervals.

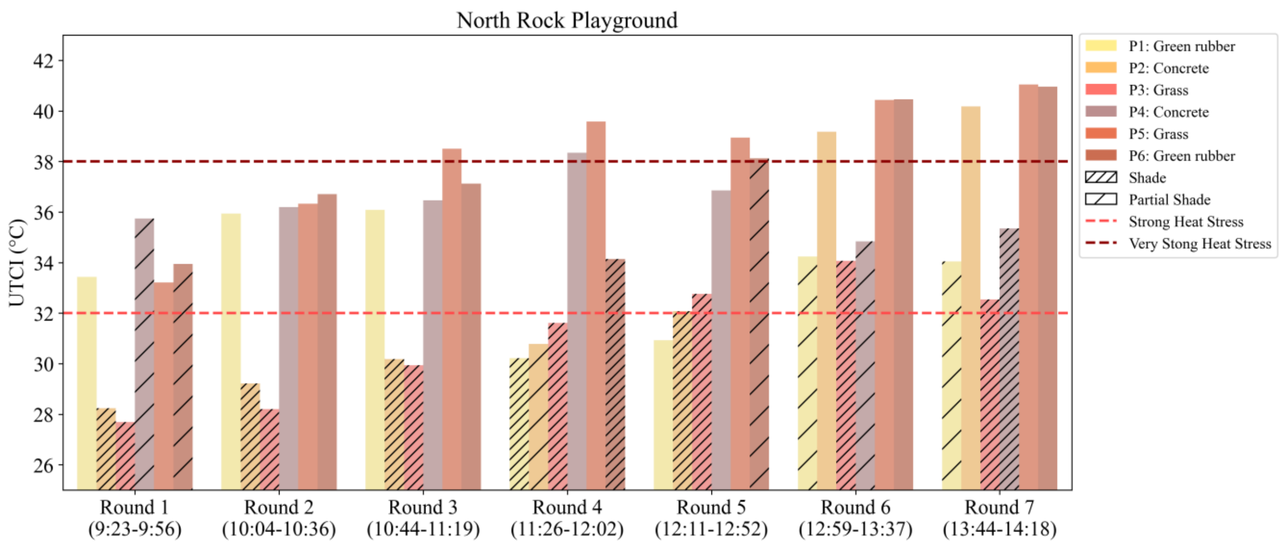


Figure S9. Universal Thermal Climate Index describing the local thermal comfort conditions at North Rocks Park Playground at different locations (as in Figure 19) and at different time intervals.

Annex B – Preliminary Report – Results for WR Musto

Too Hot to Play:

Quantifying the Impacts of Urban Climate Change on Playground Activity

Preliminary Report: Retrofit Recommendations for the Renovation of WR Musto

Version 1 | Date: 04/11/2024

Project team

Riccardo Paolini[1], Sebastian Pfautsch[2], Agnieszka Wujeska-Klause[2], Mahya Parchami[1], Negin Nazarian[1], Melissa Hart[3], Liz King[4], Nikki Woolley[5]

[1] School of Built Environment, Faculty of Arts, Design and Architecture, University of New South Wales

[2] Urban Transformations Research Centre, Western Sydney University

[3] ARC Centre of Excellence for Climate Extremes (CLEX), UNSW

[4] Cancer Council NSW, Skin Cancer Prevention Unit

[5] Cancer Institute NSW, Cancer Screening & Prevention Division

Project contacts: r.paolini@unsw.edu.au, s.pfautsch@westernsydney.edu.au

https://www.unsw.to/too-hot-to-play

Project Partners

University of New South Wales, Western Sydney University, Cancer Institute NSW, Cancer Council NSW

Funding

UNSW/WSU Alliances/Project Mezze Seed Funding – Liveable Communities. The procurement of part of the equipment was supported by UNSW Research Infrastructure Grants to the High Performance Architecture Lab (2017, 2020, and 2023).

Acknowledgements

We thankfully acknowledge the support of City of Parramatta Council | Parks and Open Space Planning with the identification of and provision of access to the playgrounds monitored in this project.

Human Ethics Approval

The project was granted human ethics approval for what concerns people counting devices, which collect anonymous counts of visitation. The human ethics approval number is: iRECS4758.

https://research.unsw.edu.au/recs

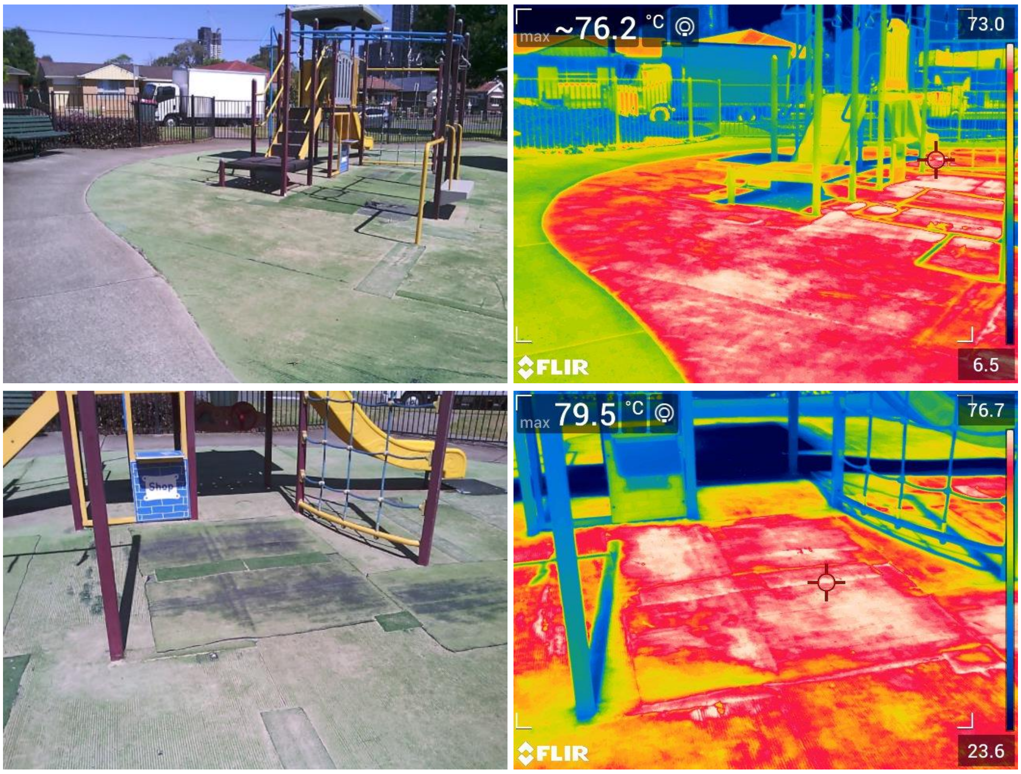
Executive Summary

Playgrounds are an important part of urban infrastructure to enable children's outdoor play and foster social interaction. However, urban overheating reduces the liveability of outdoor spaces, including playgrounds. It can become "too hot to play". Further, insufficient or inadequate shading increases the risk of unnecessary overexposure to ultraviolet radiation and, thus, the risk of skin cancer. Our research project investigates the optimal design for playgrounds that protect the community from heat and UV radiation. Therefore, we investigate three research questions:

- How do quantity and quality of shade and the overall thermal environment affect playground use?
- Are there environmental thresholds for the summertime visitation of playgrounds?
- Which design solutions can prolong playground use under a warming climate?

With support from City of Parramatta Council - Parks and Open Space Planning, we identified three playgrounds in Parramatta's Local Government Area: Binalong Park, Doyle Ground and WR Musto playgrounds. In March 2024, we installed on-site temperature and humidity sensors, and people counters that anonymously track how many people access and use the playgrounds. We also performed a preliminary field campaign, measuring the surface temperatures and main thermal comfort parameters, as well as UV exposure at the three sites. The following results were found in the initial six months of monitoring:

- WR Musto is the least accessed playground among those monitored. It is the hottest and oldest playground, without a shade.
- The surface temperatures during a warm day (maximum air temperature of 31 °C and maximum incoming solar radiation of 900 W/m^2) exceed 75 °C at WR Musto.
- Climate conditions on non-rainy days, which were excluded from analyses, were found to affect access to playgrounds due to temperature variations. Peak visitation and playground use were observed for temperatures that are commonly considered in the human comfort range (between 20 and 30 °C). This is expected to be exacerbated on extreme heat days, such as during a heatwave.
- During a hot day, the microclimate near the ground (at 0.30 m) can be 1 °C warmer than at 1.5-1.8 m. Thus, a child playing on the ground experiences a hotter air temperature than a sitting or standing adult.



Normal view and matching infrared images that document surface temperatures coded by colour, captured at WR Musto in March 2024.

Design Recommendations

Materials

- The selection of materials should also be based on their optical and thermal properties, beyond common safety considerations such as shock absorption and anti-slip surface. Testing of materials properties should be performed by accredited labs.
- Avoid artificial grass and materials with a high solar absorption coefficient, as these reach the highest surface temperatures. Research published in Building and Environment (attached) provides a comprehensive, comparative analysis of materials in this regard. For artificial, unshaded surfaces, it is advisable to use materials with a Solar Reflectance Index[i] (SRI) of no less than 29, in accordance with recommendations of the Green Building Council.
- For materials exposed to direct sunlight, select those with UV reflectance lower than 10%. Materials with a diffuse reflectance should be selected (i.e., materials with a specular reflectance exceeding 20% should be avoided, in alignment with City of Parramatta Development Control Plan on Facades). Most materials reflect at least 5-8% of UV radiation regardless of their colour, while some white cement concrete surfaces may exceed 30% reflectance in the UV range. Bare metal surfaces must be avoided, due to their potential to reflect more than 50% of UV radiation. Coated metals are generally acceptable if the UV reflectivity remains below 10%. White coatings with titanium dioxide as a pigment can display a slightly higher reflectivity (up to 15% in the UVA, but that is mostly confined to the highest wavelengths).

Provision of shade

- Provide shade to equipment as well as to resting areas
- Prioritise shade over areas for toddlers, as they are mostly exposed to UV risk and thermal discomfort
- Carefully assess the UV transmittance of the shade sails with data provided by an accredited or reputable laboratory (tested according to AS4174). Sun shades should have an ultraviolet effectiveness (UVE) rating of 95+ (If tested according to AS4399, products should have an Ultraviolet Protection Factor UPF 50+).
- Follow the recommendations provided by the Benchmarking Shade in NSW playgrounds[1] project of Cancer Institute NSW:
    - At least 70% coverage of quality shade over play equipment and nearby seating, with at least 45% of this tree shade.
    - Ideally, trees should be to the east and west of playgrounds to offer the most shade throughout the day.
    - Community survey findings (386 respondents) were clear that playground users want more shade. Tree shade was generally preferred.
    - The combination of trees and built shade was found ideal for UV and heat protection.

Note: This is a preliminary project report presenting early results and it is not intended for publication. It is shared with City of Parramatta Council before the project conclusion to support the redesign of WR Musto. A comprehensive report will be shared and published at the end of the project.

[i] The SRI is a parameter computed with the solar reflectance and thermal emittance as inputs. The calculation is performed according to ASTM E1980. The solar reflectance can be measured according to ASTM E903, ASTM C1549, or ASTM E1918. The thermal emittance can be measured according to ASTM C1371.

Project Summary

Playing outdoors is a right of children and especially important for those growing up in urban environments where access to nature is restricted. Increasingly warmer summer temperatures, in combination with widespread lack of appropriate shade and use of unsuitable materials to protect against solar ultraviolet radiation, will restrict opportunities for children to use nearby playgrounds. This interdisciplinary project investigates the conditions when play in public outdoor playgrounds across western Sydney becomes unsafe, due to the lack of shade and materials that become too hot. We combine energy flux measurements and environmental monitoring together with assessment of occupancy and human thermal comfort to evaluate the quality and quantity of shade and thermal environment under benign summer conditions. Results identify thresholds when playgrounds become too hot to play. We focus this pilot study on three playgrounds across Parramatta that differ markedly in how they are shaded and designed. Our findings will be used strategically to approach industry partners, government, and not-for-profit organisations to develop a larger systematic research project that develops basic principles for outdoor playgrounds that will remain safe for children under a warmer climate and consistently high UV radiation.

Research Report

1. Project Aims & Background

Public playgrounds contribute to the life and development of local communities and urban sociality in multiple direct and indirect ways. First, public playgrounds offer access to outdoor play – an essential element for the physical and emotional development of children[2], regardless of family income. Further, the benefits of well-designed public play areas also provide space and opportunity for connection across genders, socio-economic status, and generations. Therefore, public playgrounds are an essential component of the urban social infrastructure[3]. However, the combination of global climate change and urban sprawl is worsening urban overheating[4,5], which in turn reduces the liveability of outdoor spaces[6]. This is a particular issue in Western Sydney. Surface temperatures in sun-exposed playgrounds in Western Sydney are often hot enough to burn skin due to insufficient provision of high-quality shade and inadequate materials used for flooring materials and equipment[7]. Multiple sources have reported serious burns after contact with hot surfaces at playgrounds[7,8]. Moreover, outdoor thermal comfort is influenced by dynamic thermal pleasure[9] and 'one-size fits all' thermal comfort models used during design stages do not capture the variability in the human thermo-physiological response[10]. Also, inadequate shading will increase the risk of overexposure to harmful UV radiation of children but also parents and carers.

Substantial work with independent measurement campaigns focussing on or including playgrounds[5,7] and variability of shading[11] in Western Sydney has been carried out by this project team. Project CIs have collaborated with the community with two citizen science projects[12–14] and built Australia's first UV-smart Cool Playground in Merrylands[15]. The research team has produced ample empirical evidence that the risks related to hot surface temperature and equipment, as well as the lack of UV protection in public playgrounds, are very real and widespread. However, there is no solid quantification of the reduction in the 'playability' of playgrounds. Moreover, the influence of different parameters, such as surface temperatures and shade (natural or artificial), on the actual use of playgrounds is yet to be investigated.

Scientific and social aims

The novelty of this project lies in addressing these research questions:

- How do quantity and quality of shade and the overall thermal environment affect playground use?
- Are there environmental thresholds for the summertime visitation of playgrounds?
- Which design solutions prolong playground use under a warming climate?

This report includes preliminary results of all monitored playgrounds and is shared with City of Parramatta Council to support the redesign of the WR Musto Playground, which is undergoing renovation upon public consultation.

2. Project Scope

Within the scope. The project scope includes the comprehensive monitoring of the radiative and thermal exposure at playgrounds, assessed via local measurements with scientific-grade sensors, and smart detection of playground visitation and climate parameters. Recommendations and a prototype of integrating long-term monitoring and communication urban heat platform (potentially comprising UV radiation) that can inform playgrounds use will be developed.

Out of the scope. A sociological analysis, including a representative sample of visitors with a record of their demographic profile and interviews, is out of the scope of the project. Also, a measure of the level of engagement (i.e., intensity of play) and social interaction of visitors at playgrounds as a function of environmental parameters are out of the scope. The social cohesion within a community linked to the quantity and quality of playgrounds will not be investigated either. The health impacts of heat and solar radiation exposure are not directly addressed by this study, but relevant expert knowledge will be contributed by project partners.

3. Methods

The project approach is that of an experimental and quantitative assessment of representative playgrounds selected to fit the research questions.

3.1 Playgrounds selection

Upon consultation with Parramatta City Council and local community groups (e.g., ParraParents), three playgrounds with similar design and equipment have been identified: Binalong Park, Doyle Ground, and WR Musto. These playgrounds have no shade (WR Musto), intermediate shade (Doyle Ground), and high-quality shade (Binalong Park), provided by trees or engineered structures, and are geographically close and as such subject to similar environmental conditions (Figures 1-4). Also, playground selection is informed by demographics, socio-economic status, and expected population served. A fourth playground was selected later to replace WR Musto in consideration of its renovation and to include a playground with greater visitation and limited natural shade[ii]. The North Rocks Playground was thus selected.

Figure 1. Binalong Park.

[ii] WR Musto upgrade project: https://participate.cityofparramatta.nsw.gov.au/wr-musto-playground-replacement

Figure 2. Doyle Ground Playground.

Figure 3. WR Musto.

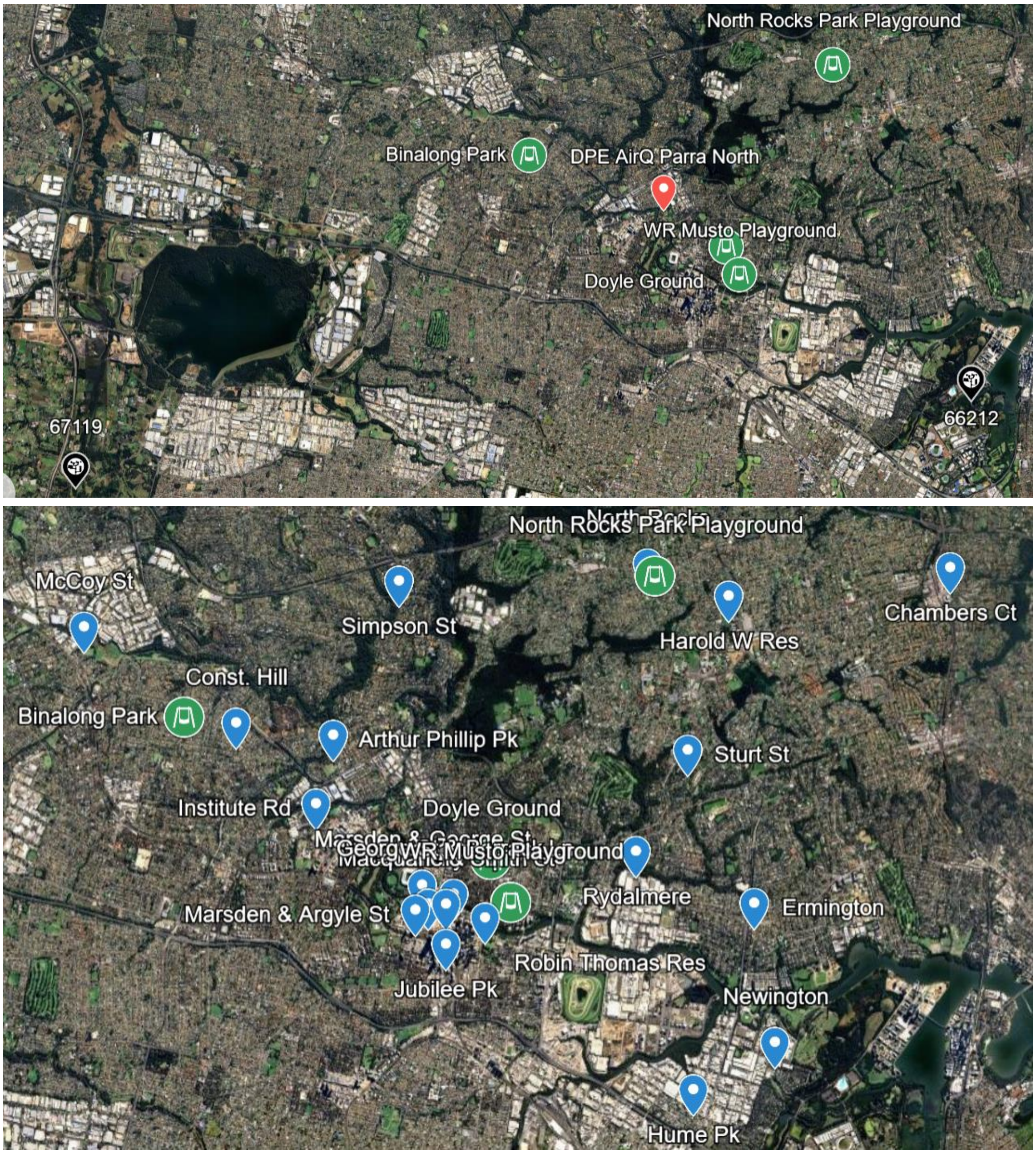


Figure 4. Location of the selected playgrounds (green swing symbol) in the Parramatta area, with the indication of the closest weather stations of the Bureau of Meteorology that supply semi-hourly data (66212: Olympic Park and 67119: Horsley Park) as well as an air quality station in Parramatta North, managed by DPE – NSW Government. The bottom image shows the playgrounds together with previous data collection in Parramatta for 1.5 years (2018-2019 Parramatta Urban Overheating Project, by UNSW), which characterise the local climate in the area. Background map from Google Earth.

3.2 Mid-term monitoring

In addition to short-term campaigns, continuous measurements include temperature and humidity dataloggers (MX2302A by HOBO, ± 0.2 °C accuracy) enclosed in a radiation shield (RS1 by HOBO), sampling data every 10 minutes. Access to playgrounds has been monitored with Farmo bi-directional infrared people counters (by Farmo). The same system was used and recommended by City of Melbourne. No images of people are collected: the sensors work like presence sensors in buildings or gate-opening infrared proximity sensors, and only record a count when a person or a group of persons transits across the field of view of the sensor. Data is inherently anonymous. The project has been granted ethics approval iRECS4758.

Temperature and humidity sensors and gate-facing people counters were installed on 27/02/2024, while additional equipment-facing people counters were installed on 15/08/2024, to increase data capturing and characterise the playground activity, beyond visitation. The equipment installed at each playground is detailed as follows.

Binalong Park (Old Toongabbie, -33.78809, 150.96549). Sensors installed (Figure 5):

- Sensor 1 on pole in front of gate close to the carpark (shade pole).
- Sensor 2 moved to sign pole (temperature & humidity sensor remains on the fence)
- Sensor 3 on pole close to sports field
- Sensor 4 moved to tennis court pole
- Sensor 5 on an aluminium pole installed by UNSW fastened to the fence (on the side of the carpark), with the sensor facing the gate
- Sensor 6 on the same pole as sensor 1, facing the swing
- Sensor 7 on a canopy pole, facing the playground equipment (slide)

Figure 5. Sensors installed at Binalong Park.

Doyle Ground (North Parramatta, -33.80641, 151.01281). Sensors installed (Figure 6):

- Sensor 1 on an aluminium pole installed by UNSW fastened to the fence (Fennel St side).
- Sensor 2 and weather station (temperature and humidity sensor) on shade pole (Butker St gate).
- Sensor 3 on canopy pole facing the swings
- Sensor 4 on canopy pole facing the playground equipment (castle)

WR Musto (Parramatta, -33.81193, 151.01595)

There is no pole to install sensors and people counter, other than the playground equipment. We installed a temporary pole fastened to the fence (to be removed after the project, Figure 7). Sensors installed: 1 people counter + 1 temperature and humidity logger.

Figure 6. Sensors installed at Doyle Ground.


Figure 7. Sensors installed at MR Musto.

3.3 Short-term campaigns (intense measurement data collection)

Short-term campaigns for each playground include the measurement at multiple locations and at different heights (0.30 m, 1.1 m and 1.8 m) of air temperature, relative humidity, and wind speed (with MetPakPro weather stations by Gill). The three measurement heights are representative of crawling children and standing adults (core body and breathing height). Measurements at multiple locations of temperature, humidity and wind speed) and mean radiant temperature, by measuring net-radiation (incoming and outgoing shortwave and longwave radiation, measured by Hukseflux net radiometers) along the three axes, quantify thermal comfort conditions, following an internationally accepted method[16] (Figure 8). Moreover, incoming ultraviolet radiation in the full sun and below the shading structures at playgrounds is measured to quantify the risk reduction of UV radiation damage to the skin (by means of a CUV radiometer by Kipp and Zonen). Surface temperatures are captured with an infrared camera, too (TG540 by FLIR). We are performing different campaigns at the different playgrounds in hot summer conditions. At each playground, measurements are performed until the signal from the instrument is stable (usually at least 90 seconds) at different shaded and unshaded spots (Figures 9-11). A rapid measurement approach allows us to capture the thermal performance of different areas of each playground under comparable boundary conditions.

Figure 8. Mobile experimental setup used to perform transects and characterise the local thermal comfort conditions and incoming solar and ultraviolet radiation. On the left, MaRTy, a mobile biometeorological instrument platform capable of measuring air temperature, humidity, wind speed and direction, GPS coordinates and mean radiant temperature using data captured in six directions by six solar and six infrared radiometers. These parameters are used to compute the local thermal comfort conditions, simulating the way the human body experiences heat. On the right, a cart equipped with solar and UV radiometers, as well as two weather stations at 0.3 m and 1.8 m from the ground.

Figure 9. Measurement locations at Binalong Park.

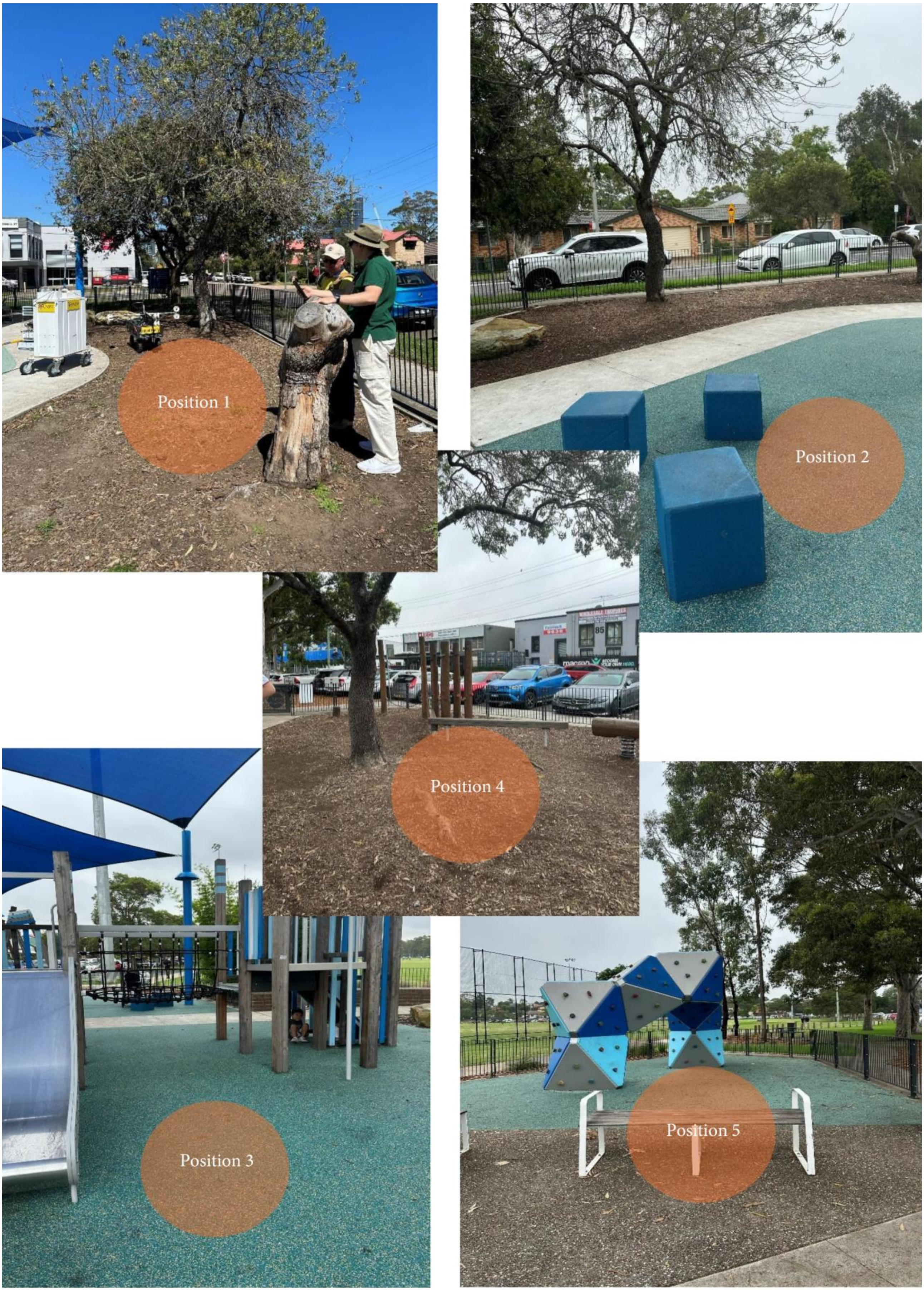


Figure 10. Measurement locations at Doyle Ground.

Figure 11. Measurement locations at WR Musto.

4. Results and Discussion

4.1 Results of the visitation and activity monitoring

Early results display a good correlation between playground visitation and playground use in the intermediate temperature range. Over the first data collection period (March – September 2024) the temperature conditions at the three playgrounds are comparable, with the air temperature slightly lower at Doyle Ground and slightly higher at WR Musto than at Binalong Park (Figure 12). Considering the number of hours above 25 °C as a simple metric, Binalong Park presents 337 hours, while Doyle Ground 322 hours and WR Musto 369 hours. Another synthetic appraisal of the cumulative temperature conditions at the different sites can be obtained by considering the degree hours, computed as the sum of the positive differences between the hourly average of the air temperature and a base temperature of 25 °C, here taken as an arbitrary temperature representative of outdoor mild conditions. In this case, over the March-September period, the degree hours are 971, 900, and 825 at WR Musto, Doyle Ground and Binalong Park, respectively. However, when comparing the peak temperatures on a hot day, these differences are within 0.4 °C (Figure 12, right). Therefore, there are recurring small differences that do not make the three playgrounds incomparable. Differences between the three sites within an hour can be due to a local airflow or variations in incoming radiation due to clouds that occur at one site slightly before that at another. Therefore, it is more appropriate to consider a 6-hour moving average to compare the different sites. In this case, Binalong Park is, on average, 0.18 °C cooler than the three-site average, while Doyle Ground is 0.07 °C cooler, and WR Musto is 0.25 °C warmer than the three-site average during the period of data collection (March-September 2024). WR Musto is in a built-up area, while the other two playgrounds are at the edges of ample sports fields, open to ventilation. We can conclude that the selected playgrounds – all within 5 km – are subject to similar surrounding climate conditions in similar suburbs, and therefore these differences are not likely to exert an influence on playground use and visitation, which is only influenced by the playground features such as equipment type, shade and materials.

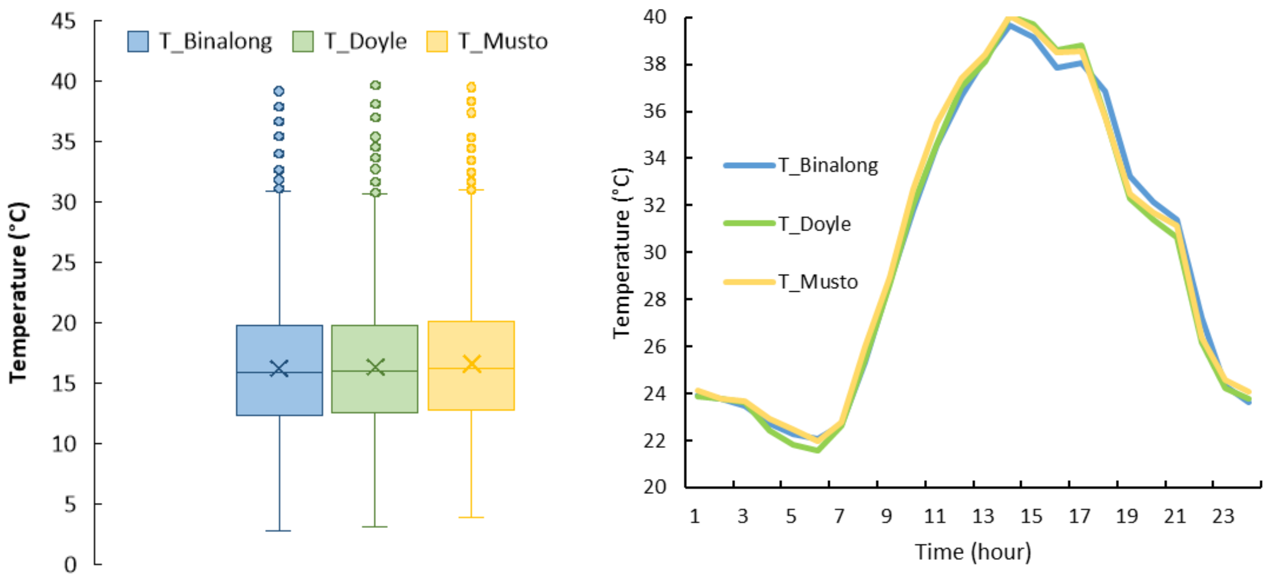


Figure 12. Boxplot of the air temperature data at the three playgrounds between March and September 2024 (left) and hourly averages of the air temperatures at the three playgrounds on 29/02/2024, a particularly hot day.

The first cluster of data we analysed refers to the period between the 1st of March (after installation was complete and commissioned) and the 10th of April 2024, which was still a relatively intermediate-warm period (Figure 13). The counts are plotted against the mean daily air temperature at the site (Figure 13 top) and against the maximum daily air temperature (Figure 13 bottom). Preliminary data seem to indicate that the peak in playground visitation at Binalong Park occurs at higher temperatures (in the 25-30 °C range) than at Doyle Ground (20-25 °C range). Whether this is influenced by a different pool of users or some false counts at Binalong Park are triggered by hot conditions (e.g., some solar angles or infrared radiation influencing the sensors), it will be clarified by longer-term measurements and calibration. Among the three playgrounds, WR Musto exhibits the lowest number of visits and the lowest temperature range of peak visits (i.e., 20-25 °C).

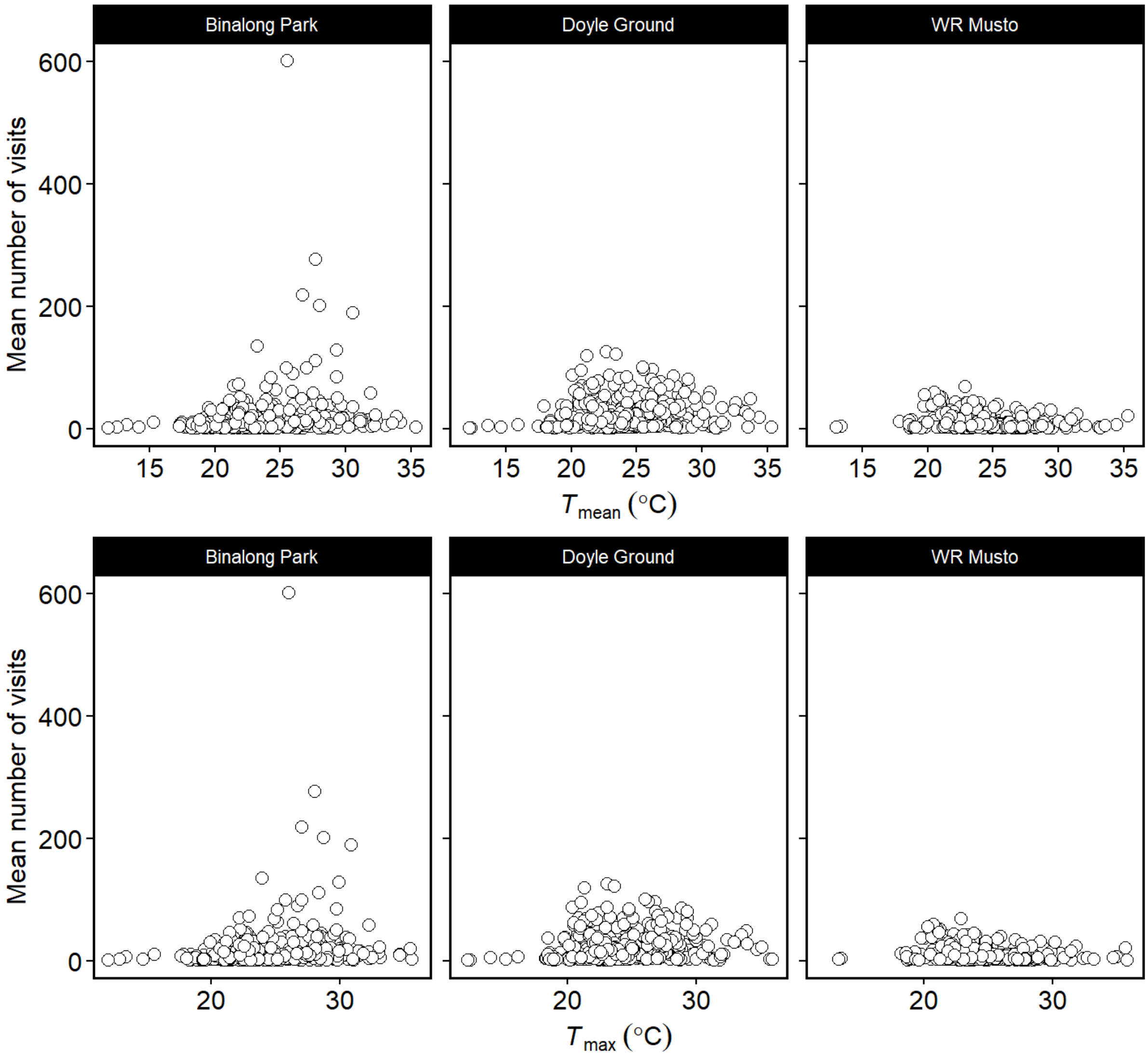


Figure 13. Counts by the gate-facing and equipment-facing sensors at the three monitored playgrounds as a function of the daily mean local air temperature (measured by the temperature dataloggers on site).

Some possible false counts due to solar radiation and position were identified. After this initial measurement period, while all sensors remained in place collecting data, a set of two sensors was used for testing and checking mechanisms for false counts off-site, and no significant anomaly was detected. The position of some sensors at Binalong Park was readjusted in August 2024, together with an additional gate-facing sensor. Both at Binalong Park and Doyle ground, additional sensors, equipment-facing, were installed on the same day.

In Figure 14, we show data collected between 16/08/2024 and 25/09/2024, when both gate-facing and equipment-facing people counters were installed. In consideration of the overall low visitation at WR Musto, we focussed this trial of the equipment-facing people counters on Binalong Park and Doyle Ground. Obviously, the equipment-facing sensors record more counts as they capture children running around equipment and using the swing. WR Musto is the playground with the lowest visitation level among the three monitored playgrounds, and the data is insufficient to determine any dependency of visitation on climate conditions. Data collected at Binalong Park and Doyle Ground display a correlation between peak activity and mild temperatures. However, we note that these are early results, and a clearer analysis will be possible only at the end of the measurement period after the summer of 2024/2025.

During the continuation of the project, we will try to clarify whether people don't go to a playground because it is generally too hot (e.g., during a heatwave) and decide not to engage in outdoor activity based on the general conditions and weather forecast or if they go to the playground and leave soon after since it is "too hot to play". In the first case, the design of the playground bears little influence as parents and guardians may decide to spend time indoors (at home or in another air-conditioned space) regardless of the playground features. In the second case, instead, the design of the playground and its thermal response influence its use and the decision to stay and return to it during subsequent hot periods in the near future, especially if the playground is perceived as a "cool place".

To clarify this issue, we will analyse data against information from the nearest weather station of the Bureau of Meteorology and will also quantify the persistence of the visitation and intensity of the activity. This is an indirect approach that doesn't involve surveys with parents/guardians, who might not have a precise recollection of multiple circumstances leading to the decision to take their children to a playground or elsewhere on a series of different days. Asking a set of parents to keep a journal and respond to surveys would not have provided quantitative information at a more substantial cost to the project.

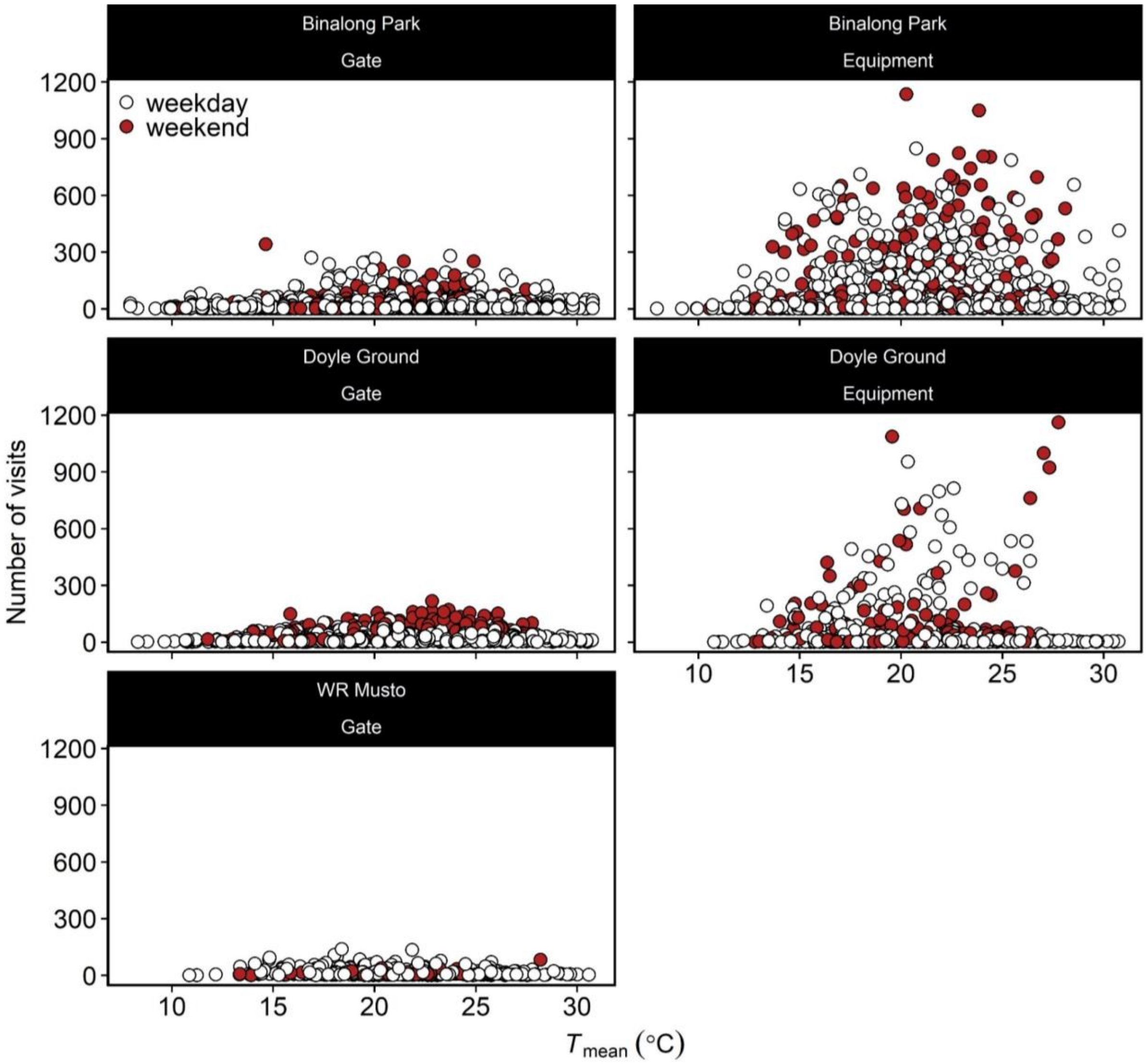


Figure 14. Counts by the gate-facing and equipment-facing sensors at the three monitored playgrounds as a function of the daily mean local air temperature (measured by the temperature dataloggers on site).

4.2 Results of the field campaign

The field campaign was conducted on 25 March 2024, a hot day with clear sky conditions. The measurements were performed on the same day at the three playgrounds, starting at solar noon and ending approximately

105 minutes later. The solar elevation was comprised between 54° and 48° during the measurement interval. Further, the incoming solar radiation ranged between 908 W/m^2 and 765 W/m^2 and the air temperature varied between 29 °C and 31.3 °C at the reference position (sports field at Doyle Ground). Therefore, we conclude that the measurements at the three sites have been performed under comparable conditions. In particular, the sky and ambient conditions during each measurement session were constant.

The first parameter that we consider is the ultraviolet radiation, which under the canopy at Doyle Ground is still more than 25% of the value recorded in full sun (Table 1). At Binalong Park, instead, the canopy reduces UV radiation to 18% of the value in the full sun. Among the three playgrounds, the canopy at Binalong Park is the most effective in reducing both the ultraviolet and the total solar radiation.

Table 1. Incoming ultraviolet (total), solar and infrared radiation measured at the three sites at different locations (measurements performed on 25/03/2024).

Time (solar)	Playground	Position	Sun/Shade	UV_{tot} (W/m^2)	Solar Rad (W/m^2)	Infrared Rad (W/m^2)
11:45	Doyle Ground	Pos 1	Sun	45.4	834.1	407.1
11:49		Pos 2	Shade	11.9	173.6	446.6
11:54		Pos 3	Shade	12.0	168.5	432.6
11:58		Pos 4	Sun (partial)	29.0	846.4	438.9
12:02		Pos 5	Sun	44.0	857.6	431.4
12:30	WR Musto	Pos 1	Sun w/ obstructions (castle)	50.2	828.5	373.0
12:34		Pos 2	Shade (partial)	8.2	31.9	520.4
12:39		Pos 3	Sun	47.9	826.1	380.3
13:12	Binalong Park	Pos 1	Shade	8.8	62.5	438.9
13:25		Pos 2	Shade	6.9	21.1	474.1
13:21		Pos 3	Sun	43.6	780.1	387.2
13:32		Pos 4	Shade (partial)	8.3	85.2	474.0

The air temperature at the three sites is relatively homogeneous, with some local differences (Table 2). The spatial differences between sunlit and shaded areas are of approximately 1 °C at Doyle Ground. The differences are smaller at WR Musto (i.e., 0.5 °C), as the shaded area is of very limited extension over the table and benches with curved metal. At Binalong Park, the spatial differences are at most of 0.9 °C, but only close to the ground, while the maximum difference between readings at 1.8 m is of 0.3 °C.

Part of this difference might be due to air overheating inside the naturally ventilated radiation shield of the weather station. However, for professional weather stations such as those we used, this effect is reported to be usually less than 0.40 °C[17,18]. In consideration of these observed differences, we will perform dedicated measurements to quantify the influence of the transitions and shading on the reading. The spatial differences in wind speed are minor and likely only due to transient variations in incoming wind intensity or local shielding (Table 3). Also spatial variations in humidity are minor (Table 4).

The most interesting differences, however, are observed in the vertical profile (Table 5). Considering the weather station on the pole at 0.30 m and that at 1.80 m, the differences cannot be ascribed to sunlit or shaded condition of the radiation shield, as both instruments are in the same position at the same time. In this case, we observe vertical differences on average equal to 1.3 °C at Doyle Ground, 0.9 °C at WR Musto and 0.7 °C at Binalong Park. This means that children playing on the ground are exposed to systematically higher air temperatures than standing or sitting adults at the same location. Further, the wind speed is lower near the ground (due to the friction and presence of more obstacles near the ground). These differences are, on average, equal to 0.6 m/s at Doyle Ground, 0.3 m/s at WR Musto and 0.2 m/s at Binalong Park. This means that a child playing near the ground is exposed to less convective cooling by the wind and, therefore, will feel heat more than a sitting or standing adult. The microclimate near the ground is also slightly drier, although these differences are minimal.

Table 2. Air temperature at 0.3 m, 1.5 m, and 1.8 m above the ground measured at the three sites at different locations (measurements performed on 25/03/2024).

Time (solar)	Playground	Position	Sun/Shade	Ta at 0.3 m (°C)	Ta at 1.5 m (°C)	Ta at 1.8 m (°C)
11:45	Doyle Ground	Pos 1	Sun	30.7	28.8	28.5
11:49		Pos 2	Shade	30.0	28.4	28.4
11:54		Pos 3	Shade	29.6	28.6	28.7
11:58		Pos 4	Sun (partial)	29.6	29.0	29.0
12:02		Pos 5	Sun	30.7	29.6	29.7
12:30	WR Musto	Pos 1	Sun w/ obstructions (castle)	31.7	31.1	30.9
12:34		Pos 2	Shade (partial)	31.7	30.6	30.5
12:39		Pos 3	Sun	31.1	30.1	30.3
13:12	Binalong Park	Pos 1	Shade	30.9	29.8	30.6
13:25		Pos 2	Shade	31.5	30.2	30.3
13:21		Pos 3	Sun	31.5	30.4	30.5
13:32		Pos 4	Shade (partial)	30.6	29.9	30.3

Table 3. Wind speed at 0.3 m, 1.5 m, and 1.8 m above the ground measured at the three sites at different locations (measurements performed on 25/03/2024).

Time (solar)	Playground	Position	Sun/Shade	WS at 0.3 m (m/s)	WS at 1.5 m (m/s)	WS at 1.8 m (m/s)
11:45	Doyle Ground	Pos 1	Sun	0.5	1.5	2.2
11:49		Pos 2	Shade	0.4	0.7	1.0
11:54		Pos 3	Shade	0.7	1.2	1.1
11:58		Pos 4	Sun (partial)	0.6	0.5	0.6
12:02		Pos 5	Sun	0.3	1.0	0.8
12:30	WR Musto	Pos 1	Sun w/ obstructions (castle)	0.5	0.7	0.8
12:34		Pos 2	Shade (partial)	0.7	1.0	1.1
12:39		Pos 3	Sun	0.6	1.0	0.7
13:12	Binalong Park	Pos 1	Shade	0.5	0.8	0.5
13:25		Pos 2	Shade	0.5	0.8	0.5
13:21		Pos 3	Sun	0.3	0.8	0.7
13:32		Pos 4	Shade (partial)	0.3	0.6	0.9

Table 4. Relative humidity at 0.3 m, 1.5 m, and 1.8 m above the ground measured at the three sites at different locations (measurements performed on 25/03/2024).

Time (solar)	Playground	Position	Sun/Shade	RH at 0.3 (%)	RH at 1.5 m (%)	RH at 1.8 m (%)
11:45	Doyle Ground	Pos 1	Sun	27.4	29.5	29.7
11:49		Pos 2	Shade	27.8	30.2	30.4
11:54		Pos 3	Shade	25.5	25.8	25.5
11:58		Pos 4	Sun (partial)	24.8	25.4	24.8
12:02		Pos 5	Sun	24.4	24.3	24.6
12:30	WR Musto	Pos 1	Sun w/ obstructions (castle)	19.9	19.9	20.0
12:34		Pos 2	Shade (partial)	19.5	20.3	20.2
12:39		Pos 3	Sun	18.6	19.0	18.8
13:12	Binalong Park	Pos 1	Shade	21.0	21.6	20.9
13:25		Pos 2	Shade	19.9	20.8	20.7
13:21		Pos 3	Sun	20.6	21.2	21.1
13:32		Pos 4	Shade (partial)	22.4	22.4	22.2

Table 5. Difference between the measurement at 0.3 m and at 1.8 m for the air temperature and between 1.8 m and 0.3 m for the relative humidity and wind speed at the three sites at different locations (measurements performed on 25/03/2024).

Time (solar)	Playground	Position	Sun/Shade	ΔT (°C) [0.3m – 1.8m]	ΔRH (%) [1.8 m - 0.3m]	ΔWS (m/s) [1.8 m - 0.3m]
11:45	Doyle Ground	Pos 1	Sun	2.2	2.3	1.69
11:49		Pos 2	Shade	1.6	2.6	0.53
11:54		Pos 3	Shade	0.9	0.0	0.37
11:58		Pos 4	Sun (partial)	0.6	0.0	0.03
12:02		Pos 5	Sun	1.0	0.2	0.53
12:30	WR Musto	Pos 1	Sun w/ obstructions (castle)	0.9	0.2	0.31
12:34		Pos 2	Shade (partial)	1.1	0.7	0.41
12:39		Pos 3	Sun	0.7	0.1	0.11
13:12	Binalong Park	Pos 1	Shade	0.3	-0.1	-0.01
13:25		Pos 2	Shade	1.2	0.8	0.04
13:21		Pos 3	Sun	1.1	0.6	0.34
13:32		Pos 4	Shade (partial)	0.3	-0.3	0.59

The measurements of the surface temperatures at the three playgrounds have confirmed what is known from previous campaigns conducted by this research group[7]. The playground flooring is designed to mitigate the impact of falls but generally reaches high surface temperatures under the sun, often exceeding 75 °C, due to its high solar absorbance (Figure 15). Uncovered soil or bark also exhibit high surface temperatures, largely exceeding 60 °C (Figures 16-18). Irrigated grass retains a low surface temperature close to the ambient temperature (Figure 17). The lowest surface temperatures are measured under the artificial shade at Binalong Park, followed by natural shade provided by trees (Figures 16-17).

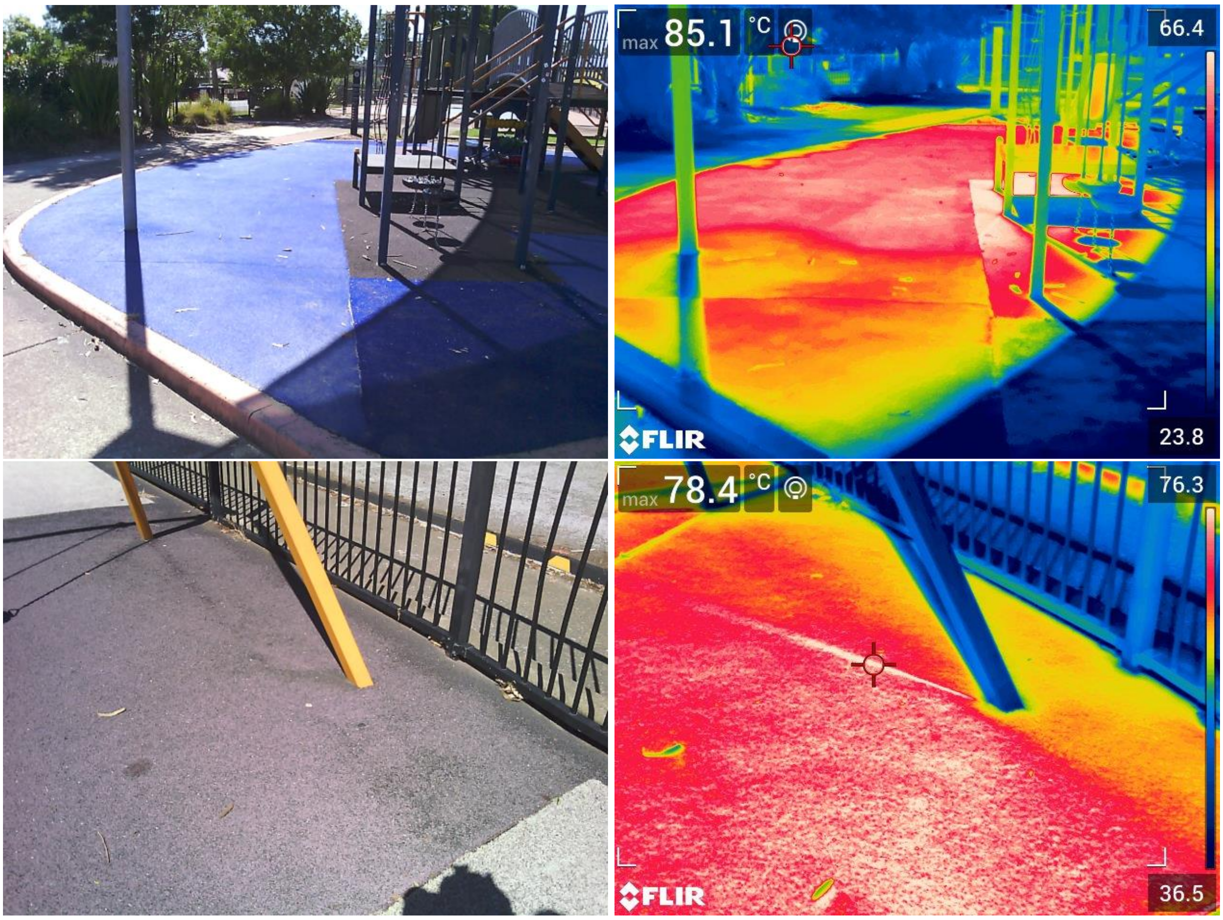


Figure 15. Visible and infrared images of various spots at Binalong Park.

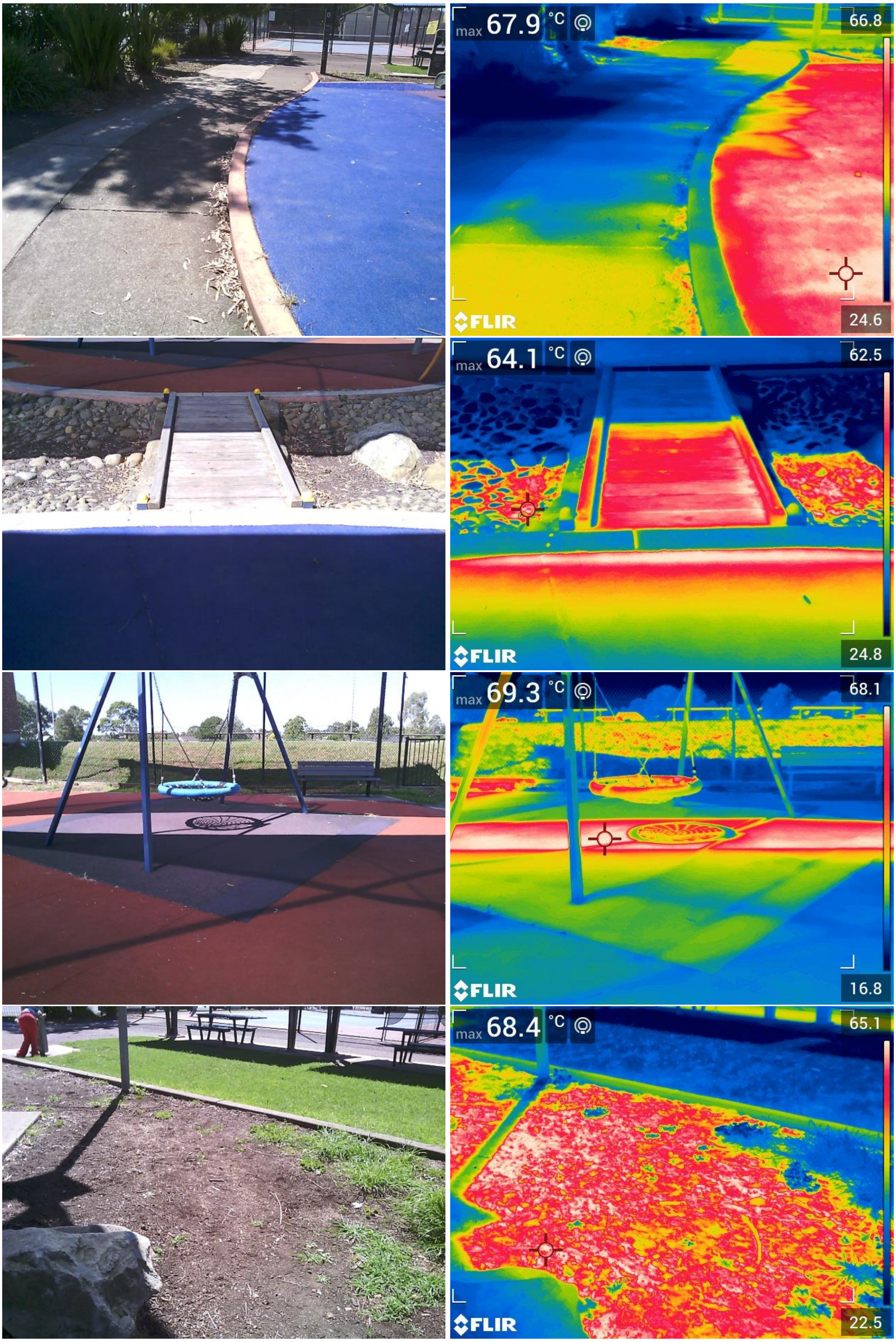


Figure 16. Visible and infrared images of various spots at Binalong Park.

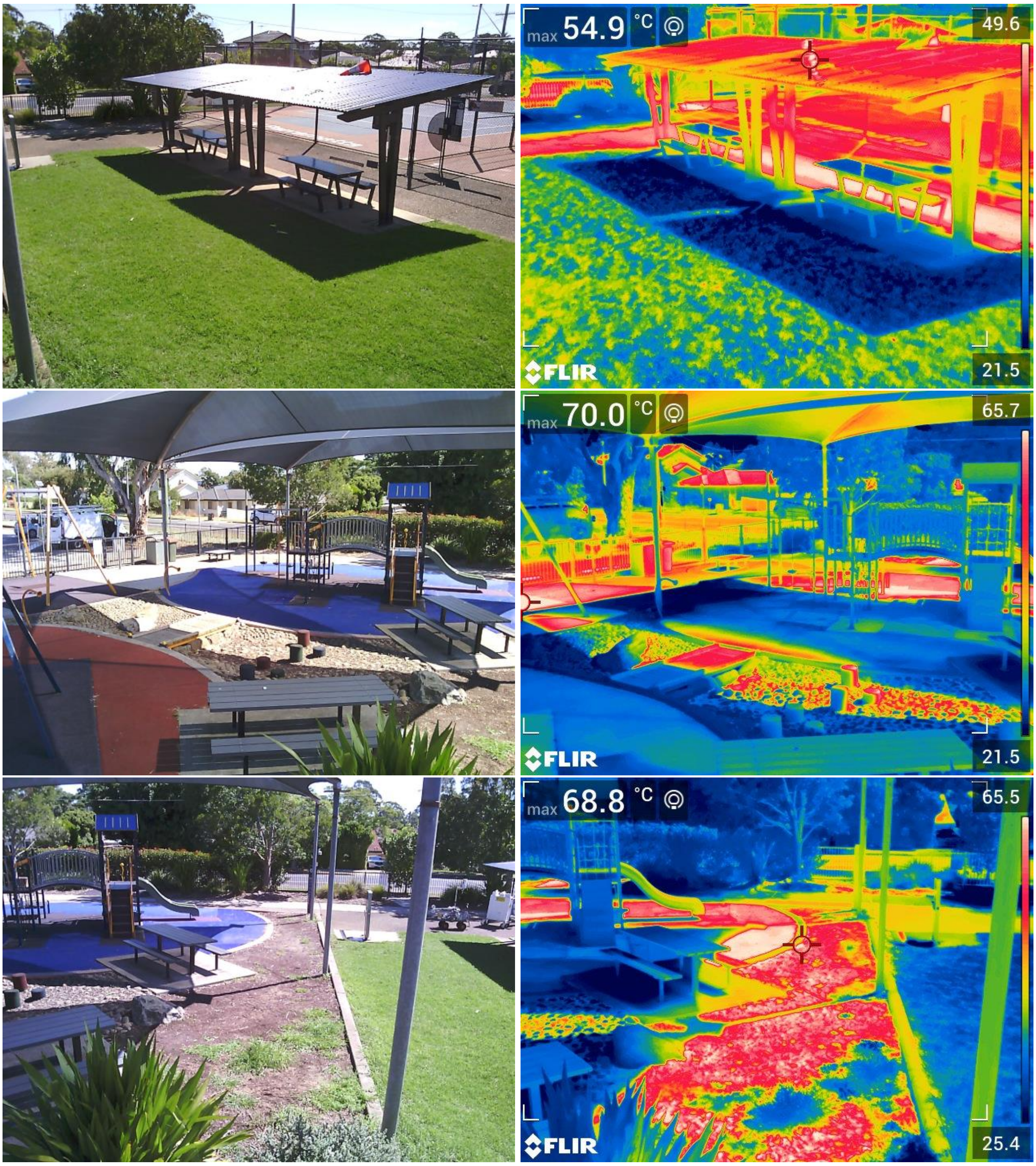


Figure 17. Visible and infrared images of various spots at Binalong Park.

The shade structure at Doyle Ground does not reduce the surface temperatures in the play area as much as the canopy at Binalong Park (Figures 18-19). The highest surface temperatures in the play area are measured at WR Musto, given the lack of shade and the use of materials with very high solar absorbance (Figures 20-21). The playground area is currently in poor repair, as the playground is listed for renovation. The shadow cast by the playground equipment demonstrates how cooler it could be if appropriate shade was provided.

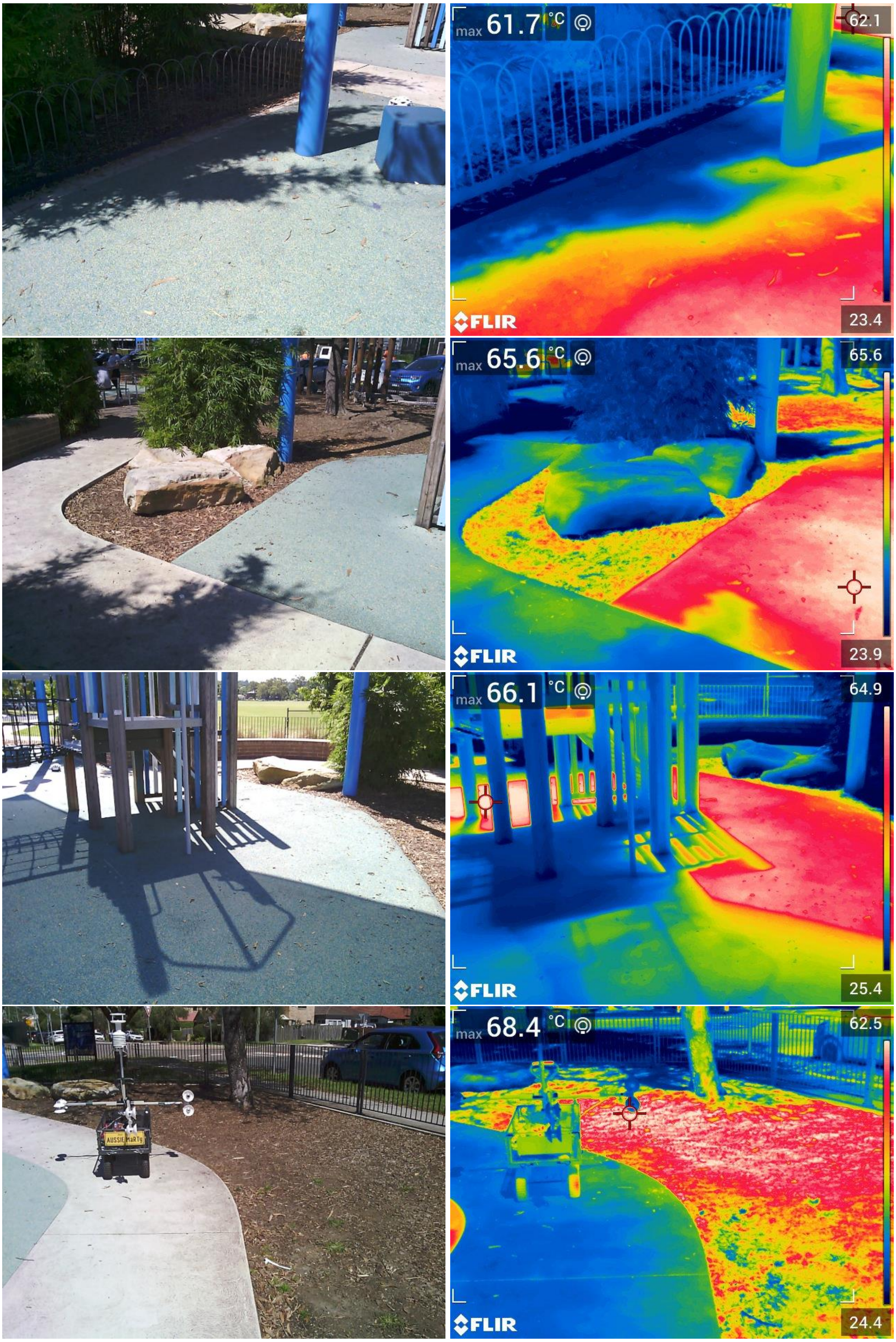


Figure 18. Visible and infrared images of various spots at Doyle Ground.

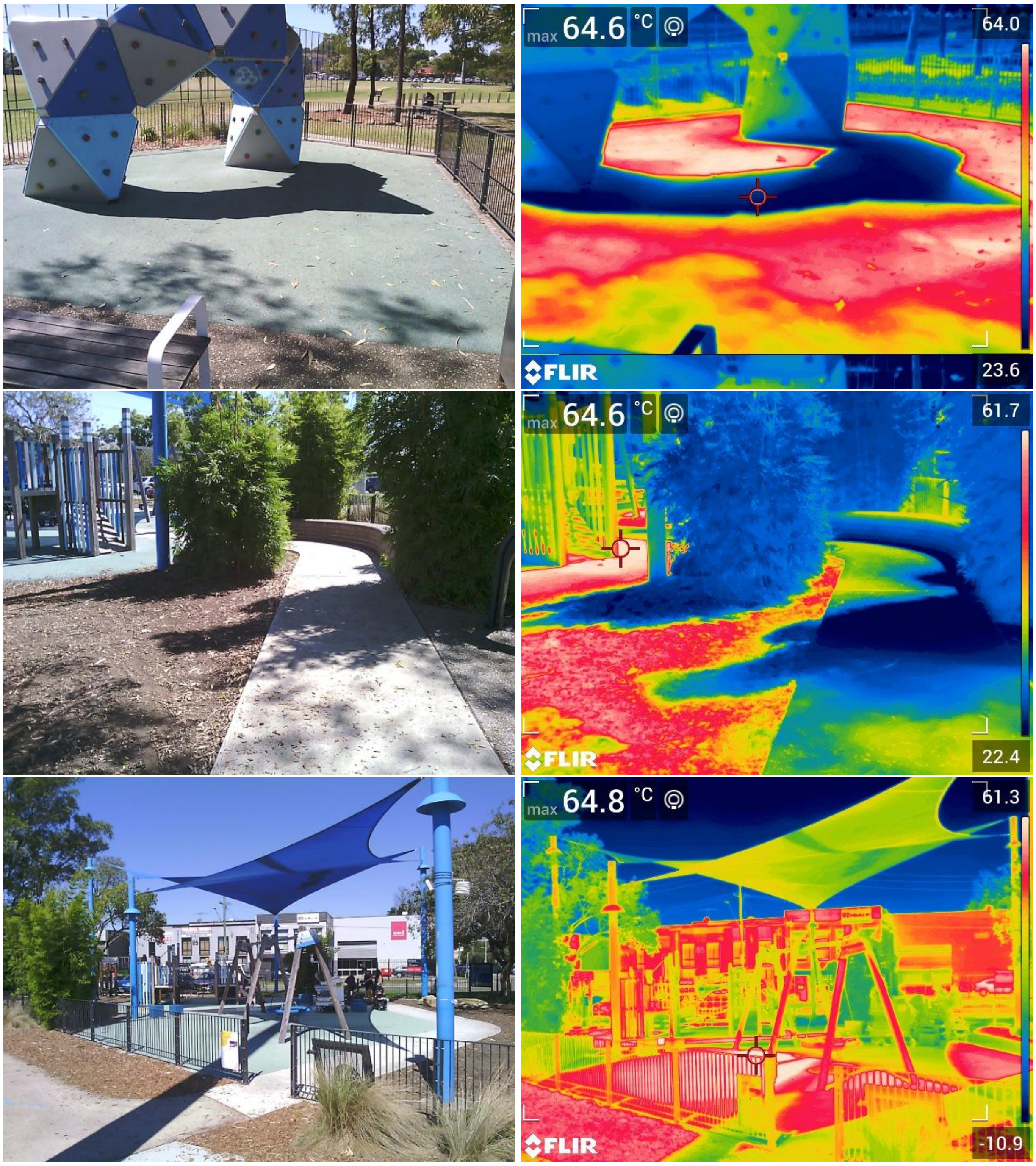


Figure 19. Visible and infrared images of various spots at Doyle Ground.

Finally, drone-captured images of the playgrounds (Figures 22-23) show how Binalong Park is provided with better shade and coverage, even if Doyle Ground benefits from a good combination of natural and artificial shade. The images also demonstrate how the canopies are partially transparent and the equipment can be seen through. This explains why even in the middle of the shade, the ultraviolet radiation is still 20-25% of that measured in full sun. While ultraviolet radiation has a greater diffuse fraction than visible and near-infrared radiation, this quantity cannot be fully ascribed to the diffuse component. As noted by Parisi et al. (2000), *the high diffuse UV component in the shade may result in high UV exposures not only to unprotected parts of the body on a horizontal plane, but also in equally high UV irradiances to parts of the body, including the eyes and face, that are not UV protected*[14].

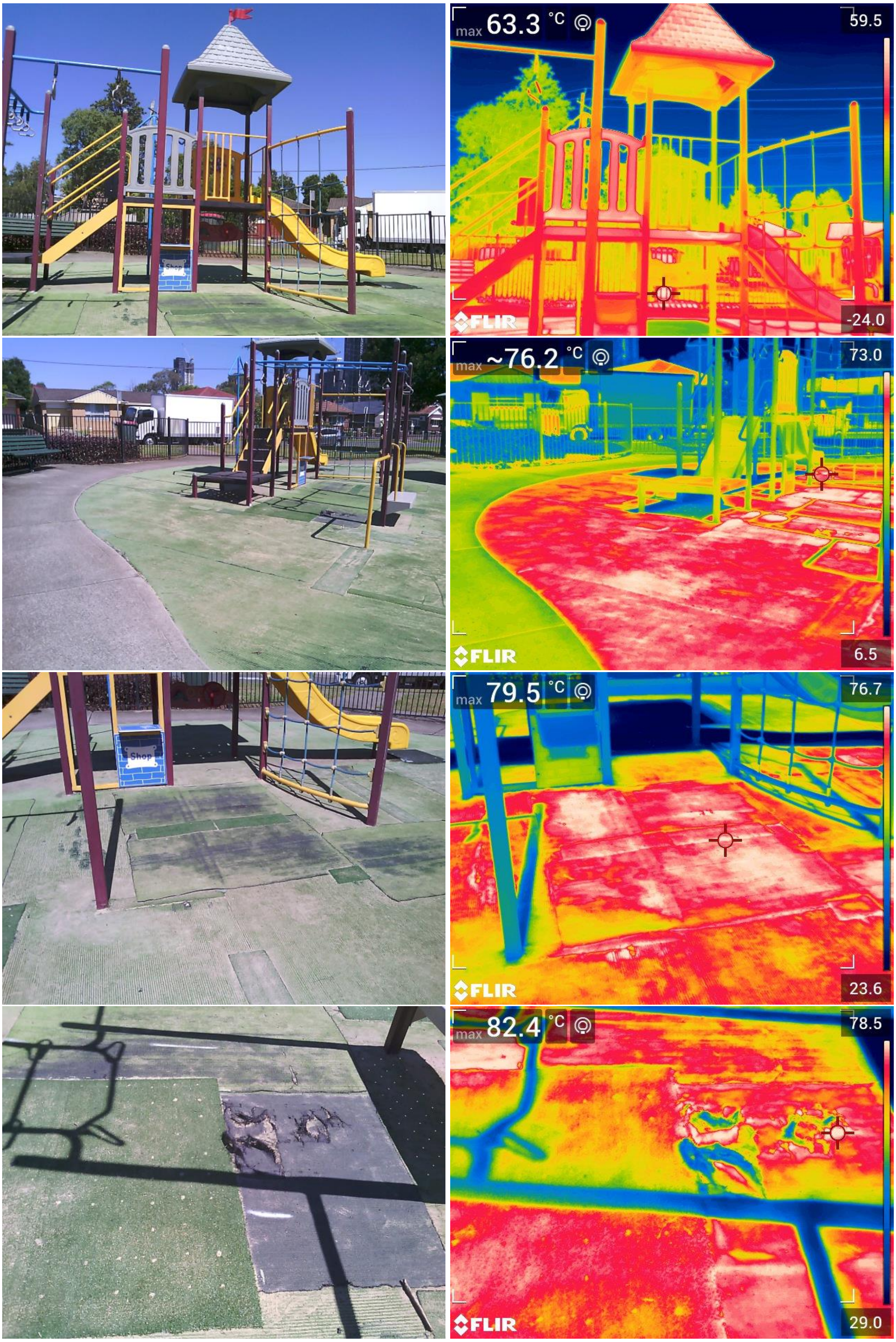


Figure 20. Visible and infrared images of various spots at WR Musto.

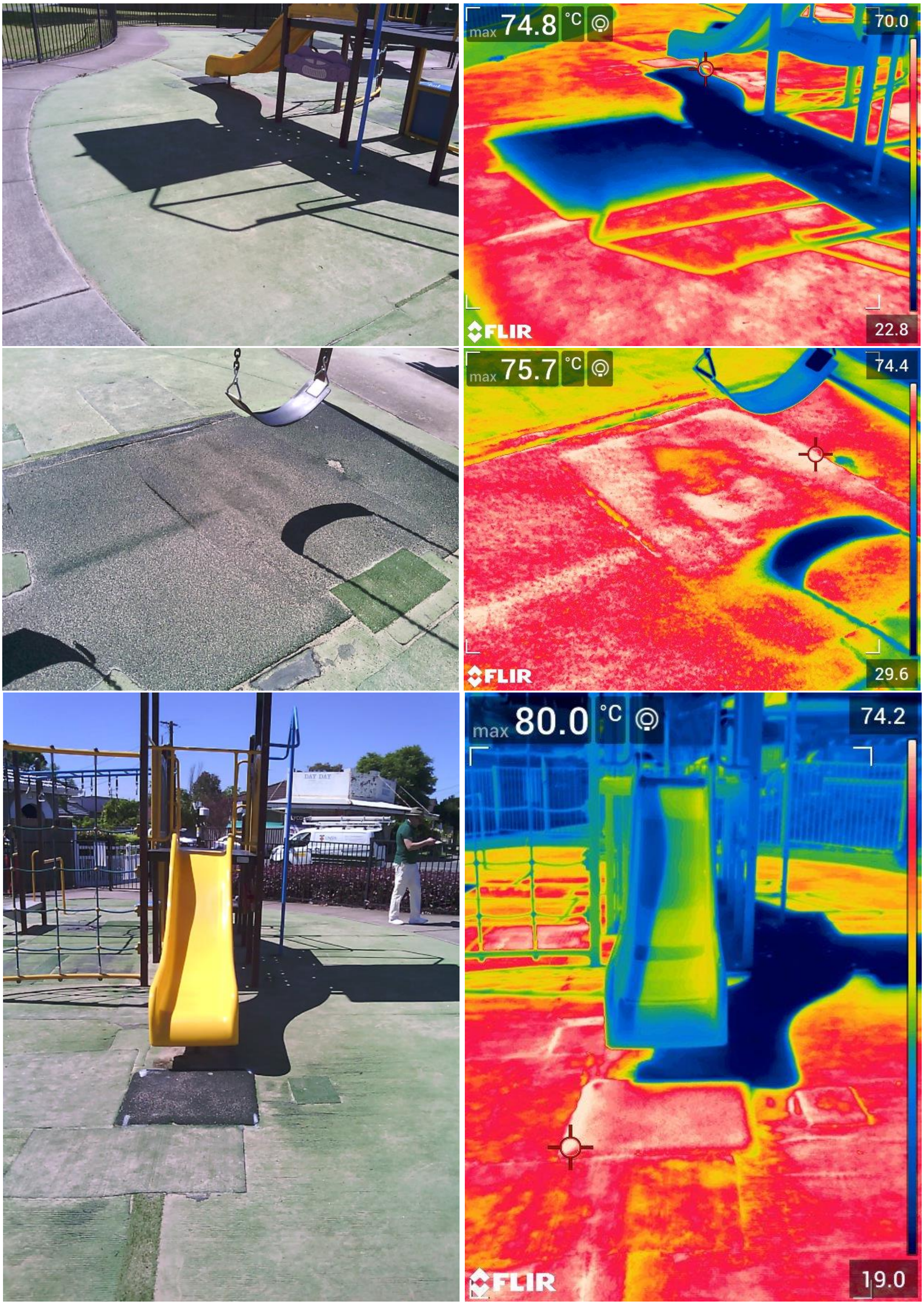


Figure 21. Visible and infrared images of various spots at WR Musto.

Figure 22. Drone captured image of the shades at Binalong Park.

Figure 23. Drone captured image of the shades at Doyle Ground.

5. Conclusions

In this report, we presented early results from our mid-term monitoring and one-day field campaigns. We identified elements to improve the measurement procedure. However, the results and collected data provide a clear indication about the overall performance of the three monitored playgrounds. The visitation and playground use data plotted against the ambient temperature capture general trends with playground visitation and intensity of the activity declining when the ambient temperature exceeds 30 °C. Among the three monitored sites, the best shade with the best coverage is provided at Binalong Park. In all cases, the shade does display some transparency, also in the ultraviolet radiation wavelength range. At the locations where we collected measurements, the shade reduced the total ultraviolet radiation to 20-25% of the amount in full sun.

The measurement setup we used allowed us to characterise the microclimate near the ground. This is the zone where children play, and we found that air in this zone can be 1 °C warmer than that experienced by an adult at the same location. Reason for this warming is warming of the air by sensible heat emitted from unshaded surfaces during a hot day. A child is also experiencing a lower wind speed near the ground, further reducing personal thermal comfort.

Our project will continue during the 2024/2025 summer, extending the data collection and including new field campaigns. The new measurements will provide further insight, in addition to these preliminary results.

References

1. Benchmarking shade in NSW playgrounds | Cancer Institute NSW. https://www.cancer.nsw.gov.au/prevention-and-screening/preventing-cancer/preventing-skin-cancer/shade-and-uv-protection/benchmarking-shade-in-nsw-playgrounds.
2. Tremblay, M. S. *et al.* Position Statement on Active Outdoor Play. *International Journal of Environmental Research and Public Health 2015, Vol. 12, Pages 6475-6505* **12**, 6475–6505 (2015).
3. Latham, A. & Layton, J. Social infrastructure and the public life of cities: Studying urban sociality and public spaces. *Geogr Compass* **13**, e12444 (2019).
4. Garshasbi, S. *et al.* Urban mitigation and building adaptation to minimize the future cooling energy needs. *Solar Energy* **204**, 708–719 (2020).
5. Santamouris, M. *et al.* Heat mitigation technologies can improve sustainability in cities. An holistic experimental and numerical impact assessment of urban overheating and related heat mitigation strategies on energy consumption, indoor comfort, vulnerability and heat-related m. *Energy Build* **217**, 110002 (2020).
6. Nazarian, N. *et al.* Integrated Assessment of Urban Overheating Impacts on Human Life. *Earths Future* **10**, e2022EF002682 (2022).
7. Pfautsch, S., Wujeska-Klause, A. & Walters, J. Outdoor playgrounds and climate change: Importance of surface materials and shade to extend play time and prevent burn injuries. *Build Environ* **223**, 109500 (2022).
8. Strong, D., Tahir, A. & Verma, S. Not fun in the sun: playground safety in a heatwave. *Emergency Medicine Journal* **24**, e9–e9 (2007).
9. Liu, S. *et al.* Dynamic thermal pleasure in outdoor environments - temporal alliesthesia. *Science of The Total Environment* **771**, 144910 (2021).
10. Nazarian, N. & Lee, J. K. W. Personal assessment of urban heat exposure: a systematic review. *Environmental Research Letters* **16**, 033005 (2021).

11. Kaluarachichi, T. U. N., Tjoelker, M. G. & Pfautsch, S. Temperature Reduction in Urban Surface Materials through Tree Shading Depends on Surface Type Not Tree Species. *Forests 2020, Vol. 11, Page 1141* **11**, 1141 (2020).

12. Rajagopalan, P., Andamon, M. M., Paolini, R. & Santamouris, M. Developing experimental protocol for collecting large scale urban microclimate data through community participation. *Engaging Architectural Science: Meeting the Challenges of Higher Density: 52nd International Conference of the Architectural Science Association 2018* 561–568 (2018).

13. Ulpiani, G., Hart, M. A., Virgilio, G. di & Maharaj, A. M. Urban meteorology and air quality in a rapidly growing city: inter-parameter associations and intra-urban heterogeneity. *Sustain Cities Soc* 103553 (2021) doi:10.1016/J.SCS.2021.103553.

14. Parisi, A. V., Kimlin, M. G., Wong, J. C. F. & Wilson, M. Diffuse component of solar ultraviolet radiation in tree shade. *J Photochem Photobiol B* **54**, 116–120 (2000).

15. Pfautsch, S. & Wujeska-Klause, A. Guide to Climate-Smart Playgrounds: Research Findings and Application. (2021) doi:10.26183/2BGZ-D714.

16. Thorsson, S., Lindberg, F., Eliasson, I. & Holmer, B. Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology* **27**, 1983–1993 (2007).

17. Nakamura, R. & Mahrt, L. Air Temperature Measurement Errors in Naturally Ventilated Radiation Shields. *J Atmos Ocean Technol* **22**, 1046–1058 (2005).

18. Yang, J., Liu, Q., Dai, W. & Ding, R. A temperature error correction method for a naturally ventilated radiation shield. *J Atmos Sol Terr Phys* **149**, 40–45 (2016).