

WESTERN SYDNEY UNIVERSITY

A NEW NATURE-BASED, FLEXIBLE AND SCALABLE SOLUTION FOR EFFECTIVE URBAN COOLING

APRIL 2026

Tensile design & construct

CUMBERLAND CITY COUNCIL

NSW GOVERNMENT



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ACKNOWLEDGEMENTS

Warami! We pay our respect to the Darug, the traditional custodians of the land on which this work took place. We acknowledge the lasting trauma that the assumption of *terra nullius* has inflicted on all Australian Aboriginal and Torres Strait Islanders peoples, past and present. Our work, as presented in this document, demonstrates that we care for people and the country today and tomorrow.

Cumberland City Council provided the land for this project and approved the structure.

The metal posts of the structure were coated with Super Therm®, a ceramic coating provided by NEOtech Coatings Australia Pty Ltd.

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SPEED READ

The need to adapt to the impacts of climate change is now universal. Countless cities and governments have identified urban green infrastructure as one possible solution to cool neighbourhoods and, at the same time, support public health and nature. Trees are well-suited to cool cities, yet they take time to grow, and many urban spaces have pre-assigned uses that are unsuitable for new trees. In a car-dependent society like that in Australia, at-grade car parks are such spaces.

Today, car parks are predominantly unshaded spaces covered in black asphalt. They have been identified as major contributors to localised urban heat island effects and reduced human thermal comfort. While omnipresent, little has been achieved in the past to cool car parks.

We designed, built and operated a new nature-based solution that cools car parks in a relatively short time and without losing a single parking space. The modular Cool Roof System (from hereon referred to as CRS) was installed at the commuter car park at Wentworthville Station in Sydney's west. The CRS spanned eight parking bays, covering an area of 138 m^2. Vines were grown at the back of the CRS in an existing garden bed. Trellis wires were used to guide the vines onto a roof made of Jakob Webnet Mesh.

Within 22 months, the vines covered more than 70% of the roof, providing 100 m^2 of shade. The equivalent area of shade produced by a newly planted tree could require more than 20 years of growth. A professional environmental monitoring program documented that the vine canopy lowered surface temperatures more effectively than the shade provided by mature trees in the car park. The CRS cooled the asphalt by up to 35°C, improved thermal comfort by up to 10°C and blocked 80% of harmful UV radiation. Its shading and cooling benefits increased when ambient air temperatures soared – the hotter the day, the more cooling from the green canopyof the CRS.

Our nature-based modular cooling system is a novel solution for adapting urban spaces to intensifying summer heat. It effectively reduces the urban heat island effect by shading hardscape. Its supreme flexibility allows implementing the CRS in many different contexts on public and private land. The system has proven benefits for cooling, blocking UV radiation and improving thermal comfort. Its cost is lowered when scaled up to cover a greater area, which, at the same time, maximises its cooling benefits. While several co-benefits are also delivered (e.g., support of local biodiversity, amenity, and reduced CO_2 emissions from parked cars), rapid and effective shade-cooling of urban spaces is the central service delivered by the novel CRS.

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1 THE PROBLEM

The issue of urban overheating – the synergistic effect of global warming and the added heat from urban densification and anthropogenic activities – is now well understood. And so are the risks associated with urban overheating.

The Australian Federal Government has released several policies that address the issue. The National Climate Risk Assessment (2025) identified heat as the most dangerous natural hazard to human health in Australia. The National Urban Policy (2024) clarifies that "Sustainable and resilient places should: (i) minimise impacts from urban heat, (ii) consider urban heat in planning and (iii) incorporate appropriate mitigation strategies".

Unshaded at-grade car parks covered in dark asphalt (from here on simply *car parks*) are a well-known source of heat in any urban environment (Pfautsch et al., 2022 and 2025). They reduce human thermal comfort, warm the air and intensify local urban heat island effects. On a clear summer day, car park surfaces can be as hot as 65-70°C.

More than 6 km^2 of unshaded car park area exists across Western Sydney alone (Prajapati, 2022). With a new airport and dependent industries and businesses, new metro and train stations, growing urban centres and their shopping and supply facilities, the area of unshaded car parks can be expected to grow. The amplifying warming effects that come with this development seem inevitable. Similar warming effects can be attributed to development around any metropolitan region or country town across Australia.

Given Australia remains highly dependent on individual car transport, car parks are omnipresent in our cities, particularly in the middle and outer ring zones. They are unavoidable and will be a key infrastructure type that urban life will depend on for decades. The same can be said for many other metropolitan regions across the world. Unshaded car parks are "despicable places" (*sensu* Pfautsch et al., 2022) when considering their contributions to urban overheating, yet they are necessary to support local communities.

2 THE SOLUTION

A brief for the ideal solution of a Cool Roof System (CRS) that can be used to reduce surface and air temperatures in car parks could read like this:

1. Build a structure that cools car park surfaces and cars without losing parking spaces.
2. The structure must also lower air temperature to improve human thermal comfort.
3. Provide good-quality shade quickly.
4. As co-benefits, the structure supports local biodiversity, is safe, robust, and lasting.
5. The structure must be flexible to allow replication at other sites and in different contexts.
6. Achieve points 1-5 with a solution that requires minimal maintenance and resources.

Tensile Design & Construct, a Sydney-based company that specialises in vertical urban greening solutions, Cumberland City Council, and Western Sydney University developed, built and tested the prototype structure for cooling car parks that met the six points of the brief (Figure 1). The prototype was funded by the NSW Government *Greening our City* Program (Stream 2: Green Innovations), commencing in 2021 and finalised in 2025.

The principle of the solution was to cool the surface and ambient air temperature using vines that form a green canopy over the car park. The vines are supported by a free-standing steel structure that connects a set of vertical trellises with a horizontal Jakob Webnet Mesh roof. The vines grow up the trellises at the back of the structure and then spread over the roof, where they unfold their cooling potential.



FIGURE 1: The prototype CRS at Holroyd Gardens in February 2026.

Today, the structure at the car park of Holroyd Gardens is fully operational, where it acts as a demonstration site for a successful, scalable nature-based solution that reduces urban heat and delivers a range of co-benefits to the council, park visitors, the local community and nature.

Cumberland City Council has a dedicated website for the project here: haveyoursay.cumberland.nsw.gov.au/holroyd-gardens-carpark

Technical details and results of the science-informed monitoring program were published in March 2025 and are freely available for download here: researchers.westernsydney.edu.au/en/publications/next-generation-cool-green-car-park-concept-for-urban-heat-resili/

3 COOL ROOF SYSTEM 2.0



FIGURE 2: Aerial view of the car park (outlined red) near the Wentworthville train station. The green pin indicates the location of the CRS. The image is oriented towards the north.

Based on the success of the prototype and learnings from operating the structure, the project partners congregated once more in 2023 to develop the next generation of the concept.

As a result of intense co-design work, project planning, and the demonstrated benefits from the Prototype (see Pfautsch et al. 2025), Tensile Design & Construct secured a Small Business Innovation and Research (SBIR) Grant from the Office of the NSW Chief Scientist and Engineer to showcase the feasibility of the solution (Phase 1) and deliver the proof-of-concept (Phase 2). This report describes work done during Phase 1 and Phase 2.

The SBIR grant program was designed to address a range of challenges, including innovative solutions to address the Urban Heat Island Effect. Cumberland City Council identified a section at the commuter car park near the Wentworthville train station as an ideal location for V2.0 of the CRS (Figure 2).

The site on the southern side of the station covers 6,550 m^2 and provides 218 parking spaces, including 4 bays for holders of disabled parking permits. Ten mature spotted gum trees (*Corymbia maculata*) and 5 camphor laurel trees (*Cinnamomum camphora*) provide 1,132 m^2 (17.3%) shade at the site.

3.1 LEARNINGS FROM THE PROTOTYPE

After building the prototype CRS at Holroyd Gardens and observing how the structure presented itself and how plants took to the trellises and roof mesh, the team was able to identify several improvements. These included:

- **Height Improvement** – Reducing the height at the back of the structure to reduce the vertical distance the climbers had to overcome before reaching the roof mesh. This change was aimed at reducing the time for the vines to grow a shading canopy.
- **Species Improvement** – Star jasmine (*Trachelospermum jasminoides*) formed excellent green columns but did not spread vigorously on the roof mesh. For that reason, only Wonga Wonga vines (*Pandorea pandorana*) and Bower vines (*Pandorea jasminoides*) were planted.
- **Growth Impulse Improvement** – It was observed that vines 'clumped' once they had reached the roof mesh. This was a clear sign that vines were lacking the impulse to continue spreading. To correct for this effect, the roof itself was angled upwards 7° from the back to the front.
- **Design Improvement** – The rectangular steel profile and square design of the frame elements used at Holroyd Gardens had an 'agricultural', purely functional optical appearance. To provide a more dynamic look, circular hollow steel beams with tapered ends and inward-pointing support beams were used instead.
- **Heat Improvement** – To further reduce the heat signature of the structure, the steel beams were coated with Super Therm®, a thermal ceramic coating material that reflects 96% solar radiation. This effectively prevented the steel structure from heating up in the sunshine. The coating was provided in-kind by NEOtech Coatings Australia.



4 PHASE 1 FEASIBILITY



FIGURE 3: Construction of the Cool-Green Car Park Cool Roof System at the commuter car park near the Wentworthville train station. (A) View to the north-eastern corner. (B) The central frame and roof mesh. (C) Detail of the construction of the frame showing the tapered end of the steel beams as a design element. (D) Metal beams before and after coating with Super Therm®.

After receiving the technical approval for the structure, its construction commenced in May 2024.

The modular CRS had four basic elements: (i) freestanding metal frames, (ii) a stainless steel Jakob Webnet Mesh roof, (iii) the vines and (iv) an irrigation system. Three metal frames were used to support a roof over eight parking bays, covering an area of 138 m^2 (20 m wide, 6.9 m deep). The structure faced from east (back) to west (front). The metal roof mesh was set under tension using wires and tension bolts. For better access and lighting, as well as to encourage upward-growth of the vines, the roof was tilted, rising from 2.14 m at the back to 2.77 m in the front. Figure 3 depicts details of the construction on 20 May 2024.

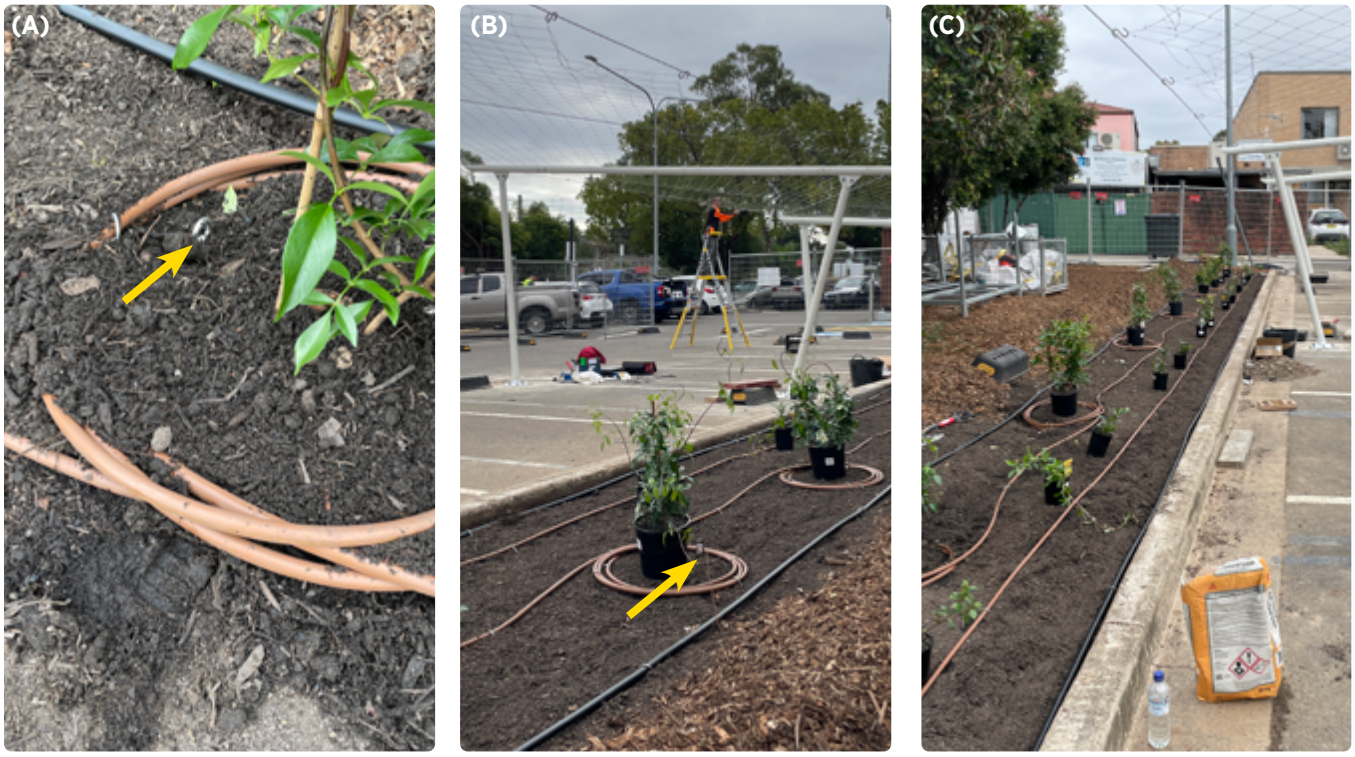


FIGURE 4: Plants and the sub-surface irrigation system. (A) Detailed view of the coiled irrigation tubing with a vine. (B) View to the northwest. (C) Planting of vines at the eastern end of the car park. Yellow arrows indicate some ground anchor points for the guide wires.

In the back of the structure was a garden bed covered with bark mulch and a row of medium-sized trees. This area was used to plant the vines. A trench was dug to provide the plants with fresh soil medium and to install the sub-surface irrigation system (Figure 4). The irrigation system was connected to a water tap at the north-eastern corner of the vegetated space. Anchors for guidewires were cemented into the ground, and vines were planted next to these anchor points. The guidewires were connected to the ground anchors and the tension wire at the back of the roof mesh. Their function was to provide direction for the leading shoots of vines to find their way upwards to the roof.

5 PHASE 2 PROOF-OF-CONCEPT

Once the construction work was finished, regular maintenance checks ensured that vines grew well, the irrigation system was working, and any damage to the structure was repaired. This phase lasted from June 2024 to March 2026. During this time, the vines covered 71% of the roof mesh (Figure 5).

The vines were planted in autumn and allowed to establish themselves during winter. Occasional weeding, removal of rubbish and twining of leading shoots around the trellis cable were the only maintenance duties necessary. With the onset of the growth period in spring, the vines quickly progressed upwards on the cables and reached the Jakob Webnet Mesh after 5 months of planting (October 2025) (Figure 6).

FIGURE 5: Progression of vine growth – from zero to 71% coverage in 22 months.



August 2024
3 months after planting



January 2025
8 months after planting



September 2025
16 months after planting



March 2026
22 months after planting

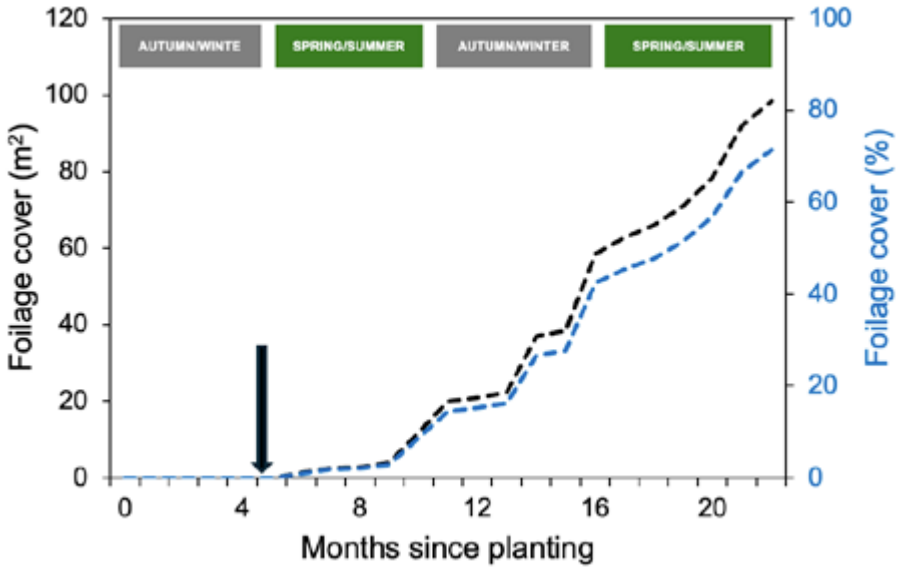


FIGURE 6: Growth dynamic and coverage of the vines. The black dashed line shows the area covered in m^2, while the blue dashed line depicts the relative coverage of the vine leaves on the Cool Roof System. The black arrow indicates when the vines had reached the roof mesh at the back of the structure (October 2024).

Both species followed clear patterns of fast and muted growth, following the usual patterns of vegetation growth in spring and late summer/ early autumn. As shown in Figure 6, once the first green leaves emerged on the top of the roof (black arrow in Figure 6), the spatial coverage of the vines did not expand much (5-9 months since planting). The second phase of vegetative growth produced more leaves at the end of summer (March 2025) before winter dormancy cooler conditions muted the growth of vines again. After being in the ground for one year, the vines had covered 12% of the structure. In the following 10 months, the vines spread rapidly to cover around 100 m^2 (71%) of the roof structure (Figure 7) with some leaders overshooting the front of the roof mesh. This indicates that vines had grown more than 8 meters in length in less than two years (Figure 8).

The growth of individual plants varied. Wonga Wonga vines generally grew faster compared to Bower vines. Both species produced large numbers of flowers (Figure 7). No complaints about vine debris on cars were received by the council. As shown in Figure 7, the provision of flowers as a food source was likely to support local biodiversity.



FIGURE 7: The Cool Roof System at the beginning and the end of Phase 2. Image A was taken in September 2024, when the climbing shoots of the vines are visible on the vertical trellis cables but have not yet reached the Jakob Webnet Mesh. Images B and C were taken in September 2025 when Wonga Wonga vines were flowering. Image D shows the final coverage of vines at the end of Phase 2 in March 2026 when some Bower vines were flowering.



FIGURE 8: In less than two years, shoots of the vines are reaching over the front end of the Cool Roof System.



FIGURE 9: Locations at the car park where near-surface air temperatures were recorded during Phase 2 (December 2025 to February 2026). Panel A shows the location of individual loggers. Panel B shows how the loggers were installed in the tree in the middle of the car park at a height of 3.2 m above-ground.

5.1 ENVIRONMENTAL IMPACTS

The following sections provide results from the environmental monitoring program that documents the cooling effect of the vine canopy. We refer to the *Project Report – Phase 1* (Pfautsch, 2024) for information about the baseline conditions across the carpark before the construction of the CRS. Subsections below are dedicated to the following metrics:

- → Ambient air temperature (5.1.1.)
- → Surface temperature (5.1.2.)
- → Human heat stress (5.1.3.)
- → Light extinction by the vine canopy (5.1.4.)

5.1.1 AMBIENT AIR TEMPERATURE

Air temperatures were recorded at four locations across the car park (Figure 9) every 10 minutes from 2 December 2025 to 6 February 2026. Although it was intended to record air temperature until the beginning of March, the measurement campaign was finalised early due to the loss of equipment at the western end of the car park (stolen logger) and the potential for further theft of loggers and associated data loss. The campaign generated 28,944 individual measurements.

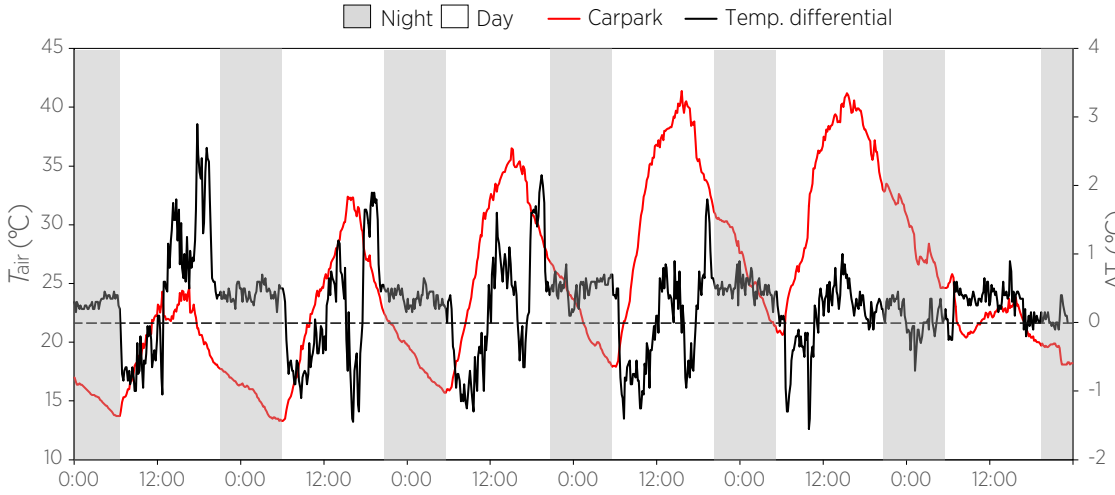


FIGURE 10: Time series of air temperature in the car park (red line) and the temperature differential (ΔT, black line), calculated as the difference between the air temperature in the central measurement location in the car park and the average air temperature measured at the two measurement locations at the eastern end of the CRS. The dashed black line marks a ΔT of zero, where air temperature at the different locations was the same. The treed area in the east had a cooler air temperature when the black line fell below the dashed line, and was warmer compared to the central location in the car park when the black line was above the zero line. Grey areas indicate night-time.

Even though the area covered by the car park was small, microclimates still differed notably among the four locations. The average air temperature differential, calculated as the mean difference between the lowest and highest measured temperatures at every time interval, was 0.6°C, which was similar to the average differential of 0.8°C recorded during Phase 1. Also, the maximum temperature differential was close to being equal in Phase 2 (4.1°C) compared to Phase 1 (4.4°C).

The differences in air temperature between the central location in the car park and the treed area at the eastern boundary were most pronounced during days when air temperatures were between 25°C and 35°C and the sky was clear. During these environmental conditions, the presence or absence of plant/tree shade, as well as the surface properties of different materials, unfolded their largest impact on air temperatures. This impact progressively diminished when ambient air temperatures became hotter, or during overcast conditions and rain events. Fig. 10 depicts these effects. The figure shows a time series of six days, during which a heatwave built up in early December 2025. Air temperatures over the car park became progressively hotter, from a peak around 25°C on 2 December to maximum daytime air temperatures above 40°C during 5 and 6 December (red line in Figure 10). At the same time, the temperature differential (ΔT) between the treed area and the centre of the car park declined and was close to zero during the peak of the heatwave, and also during 7 December when rain and clouds caused air temperatures to equalise around 20°C.

Warmer air temperatures in the afternoon of clear summer days in the vicinity of the CRS can be explained by the presence of a large area of unshaded, dark bark mulch in the garden bed between the CRS and the trees at the eastern boundary. Infrared thermography has continuously detected the warmest surface temperatures when bark mulch was unshaded (up to 80°C). This section of the car park receives full sun from noon until sunset, leading to pronounced local warming of the air in this part of the car park.

Spot measurements of air temperatures were collected during mild, hot and extreme conditions. In January and February 2026, the air temperatures under the vines ($T_{air\text{-}shade}$) were equal to those in full sun nearby ($T_{air\text{-}sun}$) (Figure 11). This is signified by the match of the red trend line for air temperature measured in the sun and shade of the vines with the 1:1 line shown in the figure. The coefficient of determination close to 1 acts as further support to conclude that air temperatures were not lower under the vine canopy.

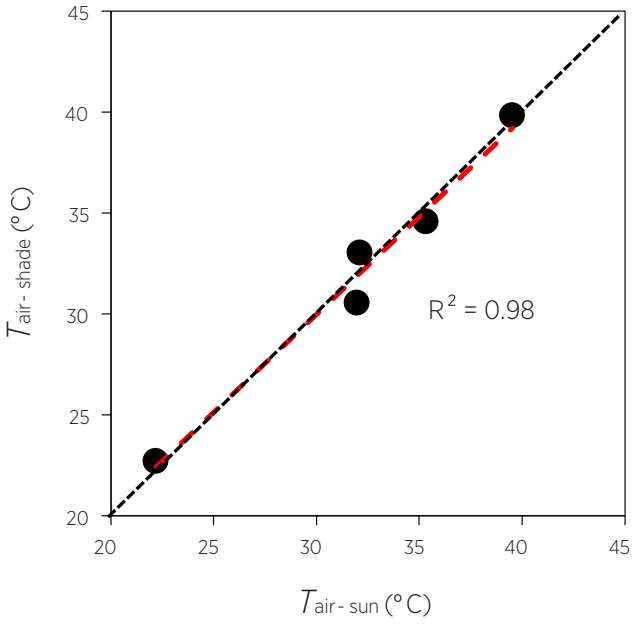
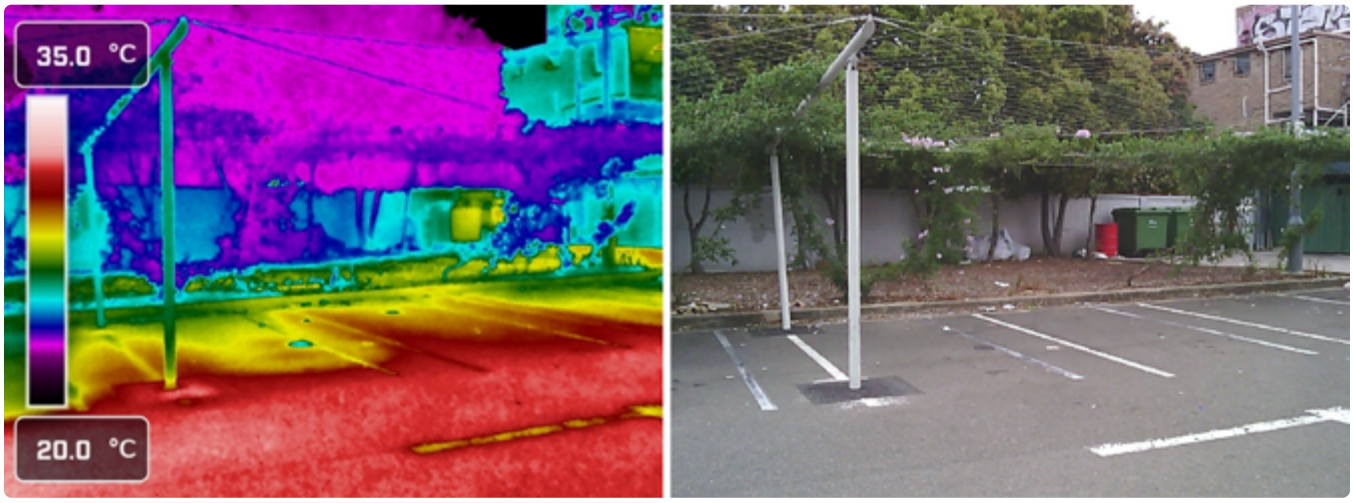


FIGURE 11: Air temperatures measured simultaneously in the open space of the car park and under the vine -covered roof of the CRS. Each data point represents the mean of 11 measurements taken over 5 minutes during midday of five days in January and February 2026. The red dashed line shows the relationship between the two parameters with its coefficient of determination (R^2). The dashed line is the 1:1 line where the air temperatures over sun-lit and shaded asphalt would be equal.

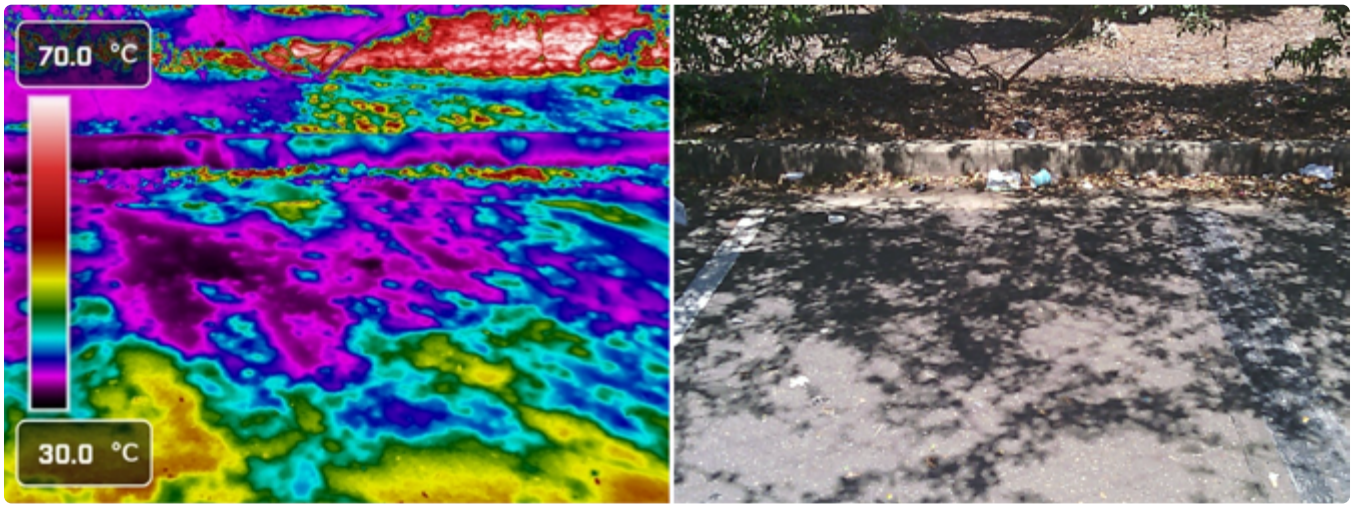


5.1.2 SURFACE TEMPERATURE

Infrared technology is regularly used to investigate surface temperatures in urban environments. Here, the technology was used to investigate the effect of plant shade on the temperatures of the asphalt surface of the car park and also on the body temperature of cars parked in the shade of trees or vines. These investigations are intended as 'proof-of-concept' for the CRS, showing the heat mitigation potential of the modular urban greening system.

Compared to air temperatures that were not different between shaded areas under the vine canopy and nearby non-shaded areas, surface temperatures were markedly lowered by the shade from the vines. This difference even existed under heavy cloud cover, yet was much smaller in magnitude. As shown in Figure 12, when direct sunshine was absent, surface temperatures of asphalt inside and outside the structure were around 27-30°C and generally 1-2°C lower under the vines compared to outside the structure. These differences are the result of diffuse solar radiation, as direct radiation is absent.

FIGURE 12: Muted surface cooling effect from vines during 13 February 2026, when conditions were overcast and cool. Only those asphalt surfaces under heavy vine cover were 1-2°C cooler. The image on the left shows surface temperatures represented by colour, with an embedded scale for reference. The right image shows the normal view of the same area.



Once direct solar radiation is present, the pronounced surface cooling effect of the vines becomes apparent. Where the shade cast by the vines is dense, surface temperatures were reduced by up to 30°C under the CRS (Figure 13). This cooling effect will apply to an increasingly larger area when vines continue to grow onto the roof, forming a denser canopy where leaves overlap. Figure 12 depicts the nature of the dappled shade cast by the vines at the end of Phase 2. Patches of dense shade are interspersed with sun flecks – areas of full and intermediate sunlight on the asphalt surface. Figure 13 also shows that the vines cast shade on the bark mulch in the back of the CRS, halving its surface temperature from 70°C to 35°C. Hence, the vines assist not only in lowering the asphalt temperatures but also limit the extent of heat radiated from the mulched area. This was previously identified as a likely contributor to warmer air temperatures in the afternoon recorded in this area (see black line in Figure 10).

FIGURE 13: Cooling effect of vine shade on surface temperatures of asphalt. The image on the left shows surface temperatures represented by colour, with an embedded scale for reference. The right image shows the normal view of the same area.

The research team extracted surface temperatures from infrared images collected during 9 campaigns where air temperatures ranged from under 30°C to over 40°C. More than 600 images were collected using hand-held and drone-mounted infrared cameras. While these images were used to analyse the cooling effect of tree and vine shade on a range of materials, including asphalt, concrete, bark mulch and a wide range of car bodies, here we focus on the cooling effect of vine shade on asphalt. This will be the most common application of the CRS and hence deserves special attention.

Infrared images were used systematically to extract asphalt surface temperatures recorded under identical conditions during each of the campaigns. Care was taken that the analyses did not rely on spot measurements, but rather on measurements covering an entire area where apparent variation in surface temperatures was captured. This was required to provide an unbiased assessment of the variation in surface temperatures. This was possible during six campaigns, using 39 images. Average surface temperatures of sunlit asphalt ($T_{surface\text{-}sun}$) ranged from 46.0-65.5°C, while asphalt surface temperatures under the vines ($T_{surface\text{-}shade}$) ranged from 31.0-44.5°C. The relationship between the two variables was statistically significant and strong (R^2 = 0.81; Figure 14), clearly showing that the cooling effect of the vines was increasing as surface temperatures of unshaded asphalt increased. This finding means that the efficacy of the CRS delivers better outcomes as summer air temperatures increase – the hotter, the more surface cooling.

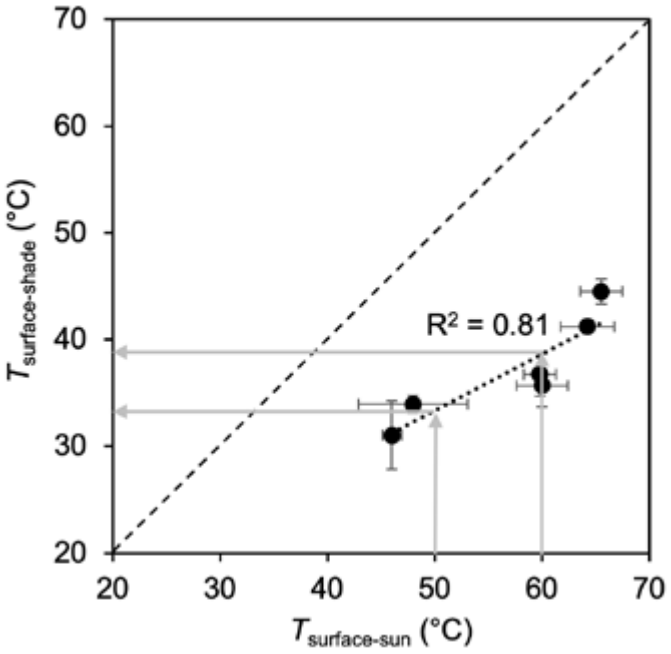


FIGURE 14: Surface cooling of shade cast by vines. The graph depicts the relationship between surface temperatures measured simultaneously on unshaded asphalt ($T_{surface\text{-}sun}$) and asphalt that was shaded by the vines ($T_{surface\text{-}shade}$). The dotted line shows the relationship between the two parameters with its coefficient of determination (R^2). The dashed line is the 1:1 line where the surface temperatures of the unshaded and shaded asphalt would be equal. The grey arrows indicate what surface temperature under the vines could be expected (i.e., T_{shade} = 33°C and 39°C) when T_{sun} is 50 °C and 60°C. Error bars show ±1 Standard Deviation.



The cooling effect of the vines extended to vehicles parked under the green canopy. As shown in Figure 15, surface temperatures of cars parked in the vine shade were reduced by more than 30°C. This reduction of the body temperature, and the associated blocking of direct solar radiation entering the car, will have cooling effects on the interior of vehicles. Unfortunately, the research team was unable to quantify these thermal benefits as this work was not funded by the SBIR grant. However, it has been shown that vehicles with combustion engines and lower cabin temperatures produce lower CO_2 emissions when started, as less cooling energy is needed to reduce cabin temperatures to comfortable levels (e.g., Scott et al., 1999; Lodi et al., 2018). The cooling effect of the vines on cabin temperatures and associated reductions in CO_2 emissions should be further investigated to fully quantify some of the co-benefits of the CRS.

FIGURE 15: Cooling effect of shade cast by vines on the body of a silver car. While the rear, top and side of the car are shaded and have surface temperatures ranging from 25-35°C, the bonnet of the car is in full sun and markedly warmer (50°C). Also, the unshaded car in the back shows much higher surface temperatures (up to 62°C). The image on the left shows surface temperatures represented by colour, with an embedded scale for reference. The right image shows the normal view of the same area.

Analyses of surface temperatures on asphalt reveal that the shade cast by the vines had a greater cooling effect when compared to the shade cast by tree crowns (Table 1). The average shade cooling effect on asphalt was 3°C greater under the vines compared to tree crowns. When calculated as the maximum cooling effect, using absolute measurements for maximum surface temperatures in the sun and minimum surface temperatures for shaded asphalt areas, the cooling benefit was larger for both plant types, yet the difference between vines and tree crowns was reduced to 1.8°C. The finding that vines are more effective in cooling asphalt surfaces likely originates from the smaller distance between the vines and the surface (2.5-3.0 m) compared to the tree crowns (15.0-20.0 m). The greater distance of the tree crowns from the ground surface allows more diffuse radiation to enter the area where shade is cast, leading to higher surface temperatures of asphalt. Additionally, the smaller distances of the vine shade to the ground also means that the shade cast does move less with the diurnal evolution of the sun in the sky. This leads to a more concentrated shade footprint of the vines in a smaller area compared to the wider movement of shade cast by mature gum trees that are 20 m tall.

TABLE 1: Comparison of the surface cooling from vines and trees on asphalt. Values are means, absolute minimum and absolute maximum surface temperatures, assessed over an area that covered several m^2 of asphalt surface. The number of measurement areas per plant type and light condition is provided in parentheses.

Date	Mean $T_{surface\text{-}sun}$	Mean $T_{surface\text{-}shade}$	Mean ΔT	Max $T_{surface\text{-}sun}$	Min $T_{surface\text{-}shade}$	Max ΔT
TREES						
21.01.2025	48.0 (4)	30.7 (2)	-17.3	49.6 (4)	28.4 (2)	-21.2
25.01.2026	64.2 (3)	47.1 (3)	-17.2	66.1 (3)	39.1 (3)	-27.0
28.01.2026	60.0 (2)	42.1 (3)	-17.9	61.6 (2)	37.4 (3)	-24.2
07.02.2026	46.0 (4)	34.1 (2)	-12.0	48.3 (4)	29.7 (2)	-18.7
Average	**54.5**	**38.5**	**-16.1**	**56.4**	**33.6**	**-22.8**
VINES						
21.01.2025	48.0 (4)	33.9	-14.0	49.6 (4)	30.9	-18.7
25.01.2026	64.2 (3)	41.2	-23.0	66.1 (3)	37.0	-29.1
28.01.2026	60.0 (2)	35.7	-24.3	61.6 (2)	31.8	-29.8
07.02.2026	46.0 (4)	31.0	-15.0	48.3 (4)	27.4	-20.9
Average	**54.5**	**35.5**	**-19.1**	**56.4**	**31.8**	**-24.6**

Lastly, the cooling effect of Super Therm® on the metal frames of the CRS was clearly detectable and particularly pronounced during hot, cloudless days. The highly reflective properties of the coating in the infrared spectrum of electromagnetic radiation kept the temperature of the metal posts and cross-beams close to ambient air temperature. Simultaneous measurements of surface temperatures of metal posts in the car park that were not covered with the reflective coating showed much higher surface temperatures. Figure 16 depicts thermal images of the sun-lit side of three different types of metal poles. The images were taken at the same time and day (10:30, 7 February 2026). At an air temperature of 32°C, the pole coated with Super Therm® had an average surface temperature of 37.5°C (absolute min: 30.6°C, absolute max: 43.0°C, n = 11 measurements), while the surface temperature of the zinc-coated pole was 46.2°C (absolute min: 41.3°C, absolute max: 52.5°C, n = 6). The black powder-coated pole had an average surface temperature of 48.1 (absolute min: 44.8°C, absolute max: 53.7°C, n = 4). It can be expected that the contribution of the coated poles of the CRS to air warming was negligible compared to other unshaded materials across the car park.

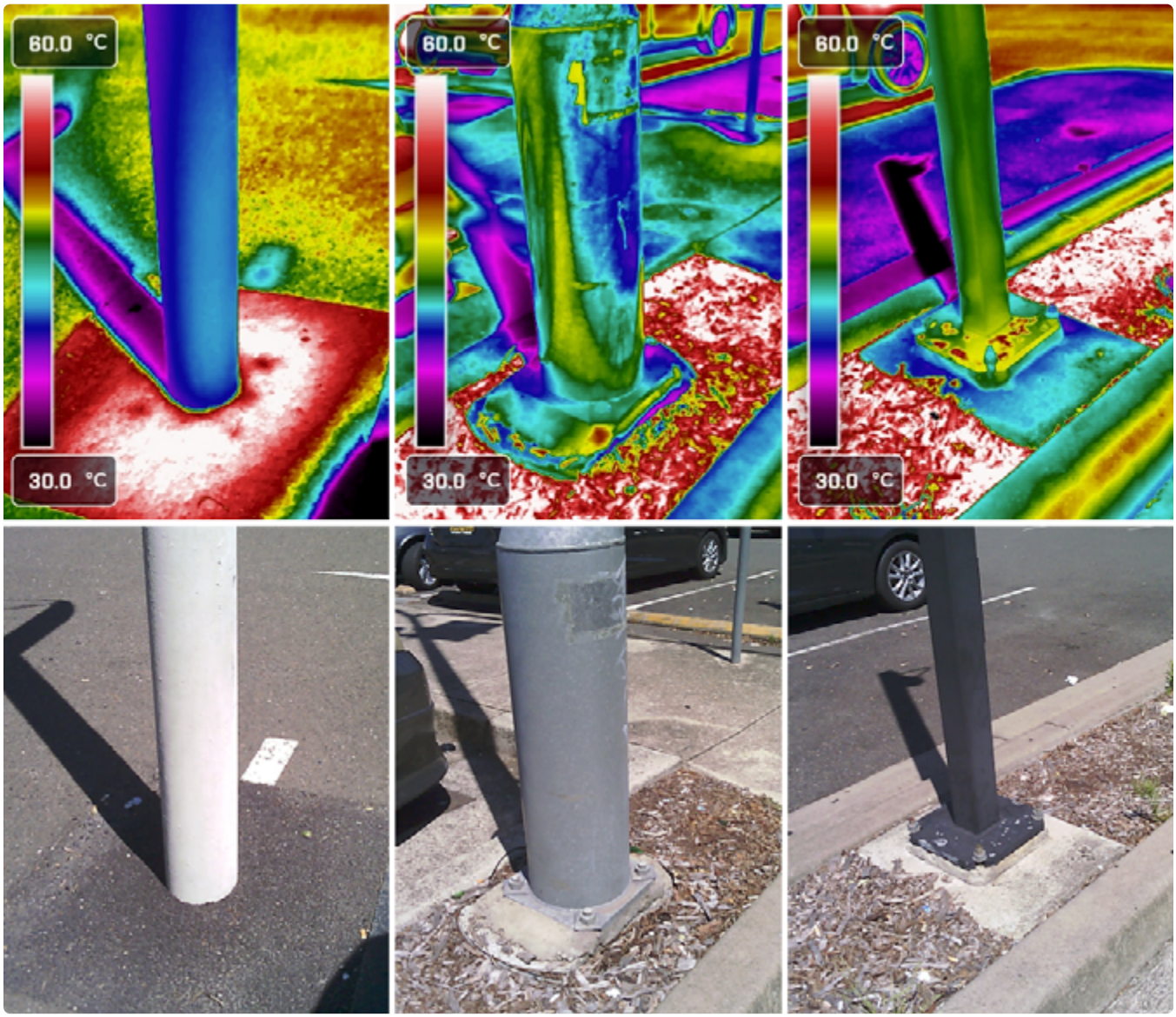


FIGURE 16: Surface temperatures of metal poles in the car park. The top row shows the infrared thermographs of three different types of poles: the CRS pole coated with Super Therm® (left), a zinc-coated electricity pole (middle), and a black powder-coated light pole (right). The surface temperatures are represented by colour, with an embedded scale for reference in the top left image. All thermographs use the same temperature-colour scale. The normal view of the poles is shown in the bottom row.

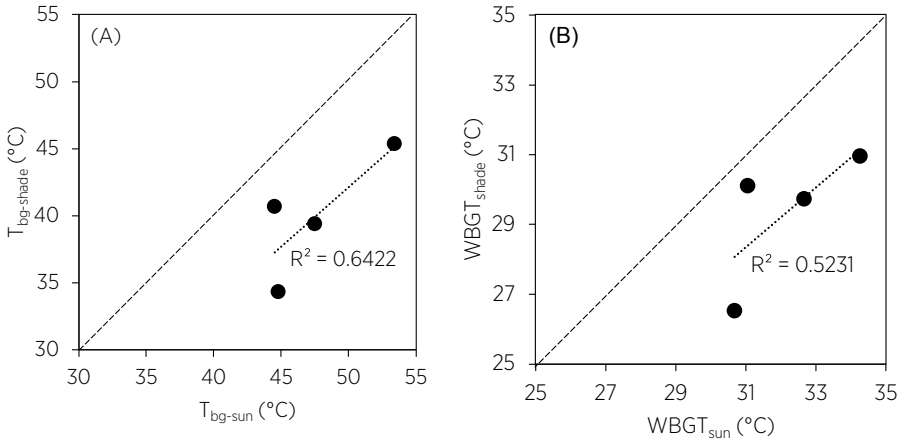


FIGURE 17: Cooling effect of vine shade on thermal comfort indices. Measurements were recorded for (A) black globe thermometers in the sun (T_{bg-sun}) and shade ($T_{bg-shade}$), as well as (B) the composite index Wet Bulb Globe Temperature, also recorded in direct sun ($WTBG_{sun}$) and shade ($WBGT_{shade}$) under the vine canopy of the Cool Roof System. Each data point represents the mean of 11 measurements taken over 5 minutes during midday of four warm or hot days in January and February 2026

5.1.3 HUMAN HEAT STRESS

The shade cast by the vines markedly improved human thermal comfort and reduced heat stress. To document this important reduction, two widely used metrics that capture thermal comfort were used: (1) the 'Black Globe Temperature' (T_{bg}) and (2) the 'Wet Bulb Globe Temperature' (WBGT). The T_{bg} records the combined effect of radiant and convective heat on a black sphere that is supposed to mimic the human body. The measurements are also influenced by ambient air temperature and the velocity of air around the instrument. Widely used in sports science and occupational health and safety applications, the T_{bg} is a rapid measure of how a person would feel in an environment. The WBGT goes a step further to represent human thermal comfort more holistically, and its calculation includes the wet bulb temperature, relative humidity, wind speed, as well as air and black globe temperatures. Clothing and the level of activity are also considered.

The shade cast by vines reduced both temperature metrics. While T_{bg} reached nearly 55°C during a campaign in late January 2026, T_{bg} in the shade was 10°C lower, yet still extremely hot as air temperatures were above 40°C. Reductions in WBGT from vine shade were still noticeable. However, their magnitude was markedly less compared to those of T_{bg}. As shown in Figure 17 (panels A and B), all measurements collected in the shade fell on the right side of the 1:1 line shown, which indicates that for any measurement collected in the sun, either T_{bg} or WBGT was lower in the shade.

Relationships between measurements collected in the sun and shade were of moderate strength, reflecting the patchy character of the vine shade. Instruments under the vine canopy can be in full, part or no shade conditions within short time intervals. As measurements were collected over a longer time interval, it is likely that microclimatic conditions, including the transmission of solar radiation through the gaps in the canopy, fluctuate. Hence, the relationships were less strong compared to those shown for air temperature measurements earlier (see Figure 11).

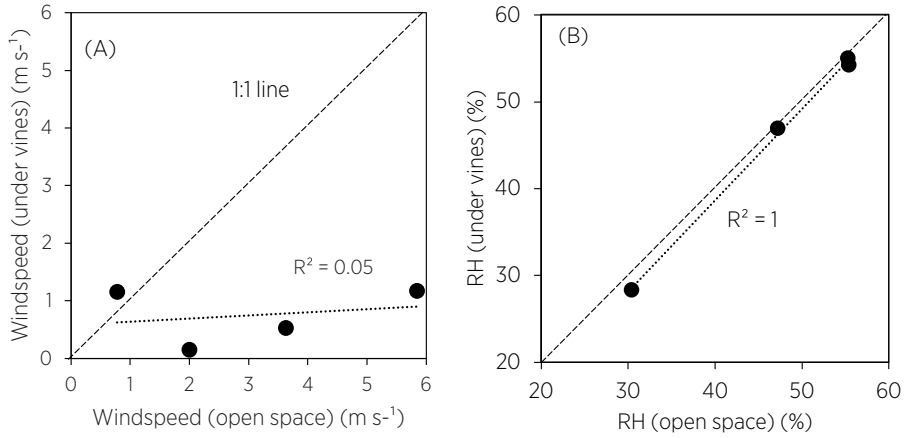


FIGURE 18: Relationships between wind speed (panel A) and relative humidity (panel B) under the CRS and in nearby open car park space. Each data point represents the mean of 11 measurements taken over 5 minutes during midday of four warm or hot days in January and February 2026. Linear regressions are shown as dotted lines, and their coefficient of determination (R^2) is shown. The dashed line shows the 1:1 line where measurements in the open space would be equal to those recorded under the vines.

Wind speed and relative humidity of the air are two important environmental variables that influence human thermal comfort, and thus T_{bg} and WBGT. Spot measurements under the CRS revealed that wind speed was markedly reduced compared to wind speeds measured a few meters away in the open car park space (Figure 18A). The lower wind speed under the structure would result in reduced thermal comfort. Hence, the reductions in T_{bg} and WBGT shown above could even be greater if air flows under the vine-covered roof were improved. How such an improvement would be achieved should be subject to further investigation and changes to the design. Compared to wind speed, relative humidity was identical under the vines and in the open car park space (Figure 18B).

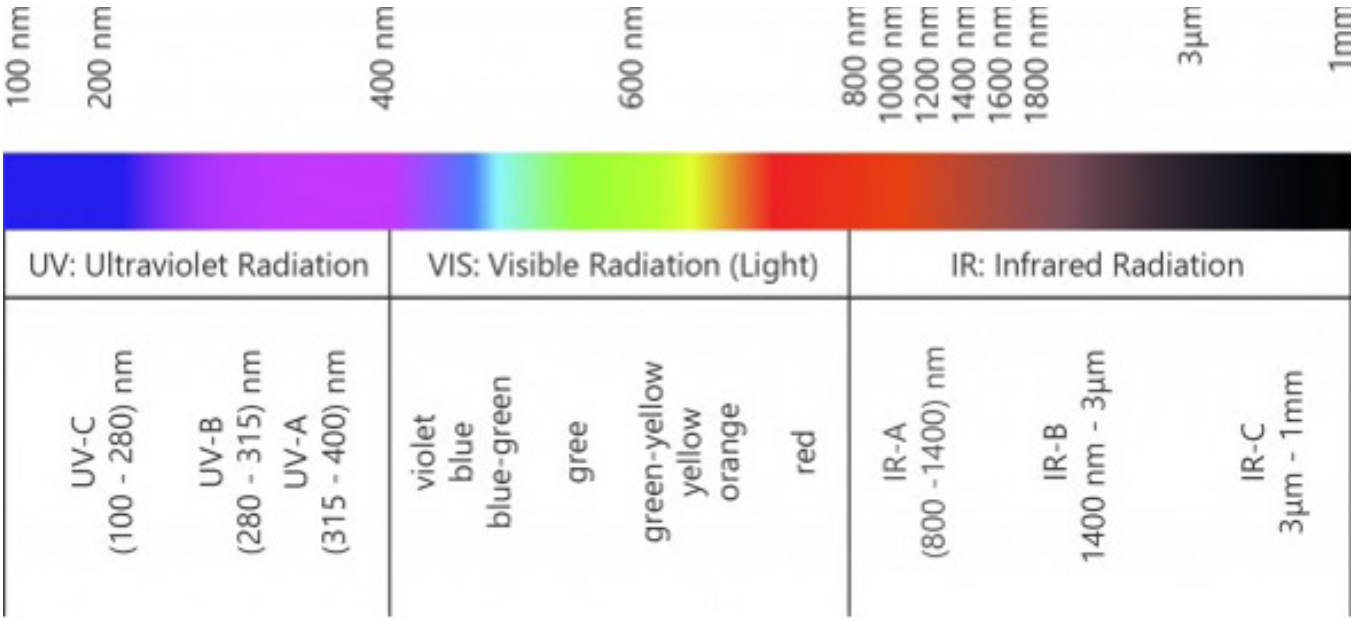


FIGURE 19: Electromagnetic wavelength ranges and their respective colours in the visible spectrum (400-800 nm). Ultraviolet and infrared radiation are invisible to the human eye, yet they can harm the human body and lead to the deterioration of asphalt surfaces (UV-A, UV-B) and contribute to local surface heating (IR-A).

5.1.4 LIGHT EXTINCTION BY THE VINE CANOPY

A portable spectroradiometer was used to determine the amount of light blocked by the vine canopy. Due to the dappled nature of the shade cast by the vines, many scans (full sun: n = 27; vine shade: n = 53) were done on four clear and one overcast day in January and February 2026. This ensured that the natural variability of the intensity of transmitted light was well captured. The spectroradiometer measured the electromagnetic radiation in the ultraviolet (UV) A and B spectra (280-400 nm), the visible light spectrum (VIS, 400-800 nm), and the near-infrared spectrum (NIR, 800-1000 nm) (see Figure 19 for more details). We note that overexposure to UV A and B radiation has negative effects on human health, by leading to sunburn (short-term effect) and skin cancer (long-term effect). UV radiation also accelerates the aging of the asphalt surface and the body of a car, which incurs maintenance costs and devalues automobiles. NIR radiation is the main type of electromagnetic radiation that heats up surfaces and objects. Shielding these from NIR radiation results in lower absorption, which in turn reduces the emission of sensible heat from these surfaces and objects. This results in reducing the urban heat island effect that causes warming of air temperatures from micro- to macro-scale in cities.

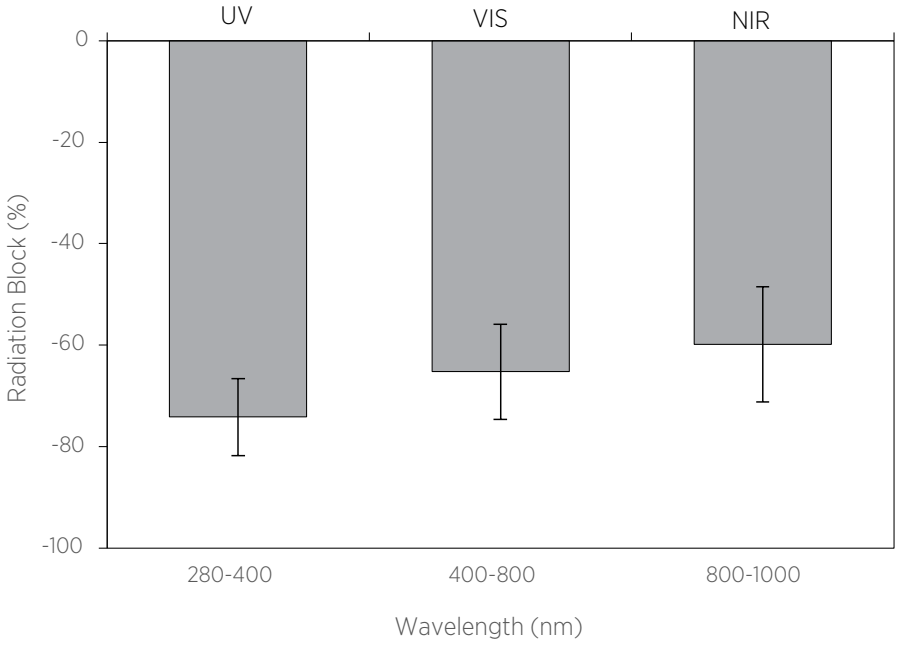


FIGURE 20: Relative radiation block of the vine canopy. Data are means of spectral scans collected during midday of four sunny days and one overcast day. Light spectra are separated into three categories: ultraviolet radiation (UV), visible light (VIS) and near-infrared radiation (NIR). Error bars show ±1 Standard Deviation.

The total amount of radiation in the open car park ranged from 260.3 W m^{-2} on an overcast day, to 2,273.3 W m^{-2} on a day with clear sky. In the open car park area during the overcast day, UV, VIS and NIR radiation were 13.7 W m^{-2}, 213.8 W m^{-2} and 32.8 W m^{-2}, respectively. Although direct solar radiation was low, the vines still blocked diffuse radiation in all three spectral ranges (UV: 53% blocked, VIS: 45% blocked, NIR: 22% blocked).

The potential of the vines to block solar radiation increased in all three spectral ranges under sunny conditions. Under the clearest sky and most intense sunshine (midday of 28 January 2026), only a quarter of the total amount of radiation passed through the vine canopy, blocking 83% of UV and 71% of NIR radiation.

During the sunny days, average UV, VIS and NIR radiation loads were 107.6 W m^{-2}, 1,533.3 W m^{-2} and 320.4 W m^{-2}, respectively. When analysing light spectra captured during these sunny days, it became clear that the vines were highly efficient in reducing UV radiation. On average, they blocked 74.2% of this type of radiation (Figure 20). Of the total amount of radiation, visible light represented between 77% and 82% of the energy measured in the open car park space and the vines blocked on average 65% of it. About 60% of the NIR radiation was also blocked (Figure 20). In alignment with the results of surface temperature reductions by the vines (see text before Figure 14), the spectral analyses also indicate that the efficiency of the vine canopy in blocking solar radiation increases as the overall intensity of the radiation increases – the more sunshine, the better the shade quality cast by the vines.

6 CONCLUSION

Phase 2 of the CRS has clearly demonstrated that our nature-based structure delivered its intended purpose. Surface temperatures were reduced significantly under the green canopy, which resulted in improved human thermal comfort and cooler cars.

In situations where natural shade is needed but space is not available to plant trees, or natural shade is needed fast, the design developed and tested here offers an effective solution. It was demonstrated that it is possible to create 100 m^2 of ground-projected shade in less than 2 years – a remarkable success with lasting positive impact for the site's microclimate. If maintained well by the Cumberland City Council, it is reasonable to expect that the CRS will be fully grown over by the end of 2026, providing its cooling benefits for many years.

Importantly, the design is flexible and scalable, which lends itself to countless applications inside, but also outside of unshaded car parks. We envisage growing vines for natural shade around hospitals, public transport infrastructure, retail hubs and DIY outlets, or at early-learning centres, schools and universities where people spend much time outdoors. Vines will grow well in irrigated planter boxes where garden beds are unavailable (e.g., on the top-level parking deck of a shopping centre).

Nothing stands in the way of implementing the solution on private land. The combination of vines, trellises and Jakob Webnet Mesh can be used to construct carports, and provide shade for walls and windows, cover pergolas, decks and other private outdoor spaces. The co-benefits generated by those structures, including the support of nature and aesthetic appeal, are delivered by all of them.

The Cool Roof projects at Holroyd and Wentworthville have clearly shown that improving urban microclimates and combating urban heat island effects with plants is possible today, and highly effective. Creating green canopies with vines to provide more shade in our overheating cities is thus an original demonstration of effective adaptation to climate change impacts. As long as irrigation is provided, the solution will deliver cooling, UV protection and lower NIR radiation in any background climate and settlement.



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