Report for the Department for Environment and Water, Climate-KIC Australia and the City of Adelaide

Cool Road Adelaide Project

11 August 2020

EDGE

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Executive summary

Cities are vulnerable to the effects of heat due to often limited cover of living infrastructure and a large amount of heat absorbing and low solar reflectivity surfaces, such as roads and buildings. Climate-KIC Australia in partnership with City of Adelaide and the Department for Environment and Water are investigating options for the cooling of spaces in the public realm, including road surfaces to help prepare to adapt to the effects of climate change, including increased average temperatures and an increase in extreme heat.

The use of cool road sealants (heat reflective road seal coats) have been trialled and adopted as a heat mitigation strategy in many different parts of the world. Recognising the potential benefit of this approach, a trial was established to assess the heat reduction capacity of cool roads in Bowen Street, Adelaide. Three cool road sealants were applied to the road surface and compared to a traditional asphalt control. The trial aimed to showcase the heat mitigation properties of cool road sealants and to compare the efficacy of each of the three treatments in comparison to one another and the asphalt control.

Edge Environment, working with AirborneLogic and Endev Geographic, conducted two separate trials to determine the impact of three cool road sealants on both surface temperature and air temperature. Two of the cool road sealants, JetCool and JetBloc (Treatments 1 & 2 respectively) were produced and provided in kind by Fulton Hogan. The other product, CoolSeal (Treatment 3) is produced in the USA by GuardTop and applied in Australia by SuperSealing. The first trial utilised thermal imaging cameras to record the surface temperature of all three treatments and the asphalt control. Surface temperature was recorded in four different phases: pre-treatment daytime, pre-treatment night-time, post treatment daytime and post treatment night-time. The second trial recorded air temperature at 10cm, 100cm, 150cm, 200cm and 250cm above the road surface and collected localised surface temperature data.

To supplement field trials, the CRC for Water Sensitive Cities Scenario Tool was used to explore the potential impact of applying cool road sealants at a whole of city scale. The Scenario Tool is a planning-support tool that enables users to assess the evolution of urban infrastructure, water networks and population demographics over time. The Extreme Heat Day and TARGET modules were used to explore impacts on surface temperature and air temperature respectively.

This study is understood to be the first in Australia to capture day and night time surface temperature data, providing the evidence that cool road sealants can contribute to temperature reduction on the road surface during the day and into the evening after sunset. The results of the study include that:

- All three cool road sealants showed a reduced surface temperature relative to the control asphalt road. This was 8.65°C, 4.95°C and 2.6°C for Treatments 3 to 1 (respectively) during the day and 4.2°C, 2.9°C and 1.5°C during the night.
- New asphalt roads were found to be not just hotter than cool road sealants, but also had temperatures upwards of 6°C hotter than aged asphalt.
- The average surface cooling achieved by Treatment 3 compared to the control asphalt surface during the day was 8.65°C. This is the highest cooling effect observed for a cool road sealant of all recent trials conducted in South Australia, however, it is still lower than some of the cooling benefits suggested by product manufacturers in Australia and overseas for this type of treatment.
- The extent of impact of treatment type on air temperature was inconclusive, although there was a clear difference in temperatures across the air column with higher temperatures closer to the ground compared to a height of 250cm. Whether the lack of a detectable impact is a real effect or due to local weather conditions on the day of the assessment requires further consideration.
- According to the CRC for Water Sensitive Cities Scenario Tool, widespread use of the most effective sealant could generate a near 1°C surface cooling at a whole of city scale. While this level of surface temperature cooling across the urban area may not seem substantial, it could lead to substantial reduced energy consumption during heat waves, which is worthy of further research.

- There was widespread interest in the cool road trial across the community with strong engagement though social media platforms. Even though direct engagement via the survey was low, the responses were in the majority positive with no negative feedback regarding the products.

Contents

1 Introduction

Cities are vulnerable to the effects of heat due to often limited cover of living infrastructure and a large amount of heat absorbing and low solar reflectivity surfaces, such as roads and buildings. Heat absorbing surfaces contribute to an artificially high temperature in cities, known as the Urban Heat Island (UHI) Effect (US EPA 2005). Areas can also form within cities that experience higher temperatures than the surrounding urban landscape.

In preparing to adapt to the effects of climate change, including increased average temperatures and an increase in extreme heat, Climate-KIC Australia in partnership with the City of Adelaide and the Department for Environment and Water are investigating options for the cooling of spaces in the public realm, including road surfaces.

Whilst climate change is not directly related to the UHI effect, the impact of heat in cities is predicted to be exacerbated due to the effects of climate change (Bureau of Meteorology and CSIRO 2018). The UHI effect has impacts on the health of humans and ecosystems as well as city liveability.

Due to many factors such as footpaths, carparks, awnings and above and below ground services, street trees and green/living infrastructure can be a significant challenge to plant and maintain in built-up urban landscape, therefore alternatives for cooling urban areas are being investigated.

Aerial heat mapping conducted in Adelaide in 2017 and 2018, clearly demonstrates the heat storage capacity of roads and the impact that roads have in absorbing, storing and releasing heat in the urban environment (Seed Consulting et al. 2018).

The use of cool road sealants (heat reflective road seal coats) have been trialled and adopted as a heat mitigation strategy in many different parts of the world. Cool road sealant manufacturers claim their products increase the albedo of the road surface, reflecting heat from the road surface, reducing the surface temperature of the road and cooling the surrounding environment.

A trial was established to assess the heat reduction ability of cool road sealants in Bowen Street, Adelaide. Three cool road sealants were applied to the road surface and compared to an asphalt control. The trial aimed to showcase the heat mitigation properties of cool road sealants and to compare the efficacy of each of the three sealants in comparison to one another and the asphalt control.

This report presents the results of:

- Surface temperature assessment (Section 2);
- Air temperature assessment (Section 3);
- Modelled heat island analysis (Section 4);
- Community stakeholder feedback (Section 5).

The results are discussed in the context of other similar studies in Australia and internationally.

While not a specific focus of this study, a description of the road surface following application of the treatments is provided in Section 6.6 based on analysis undertaken by the City of Adelaide.

2 Land surface temperature assessment

2.1 Methodology

The analysis of the datasets utilised a dual control Before-After-Control-Impact (BACI) experiment design (Green, 1979), using both spatial and temporal controls. Four surfaces were analysed, including the three treated surfaces (T1, T2, & T3) and one control surface (C) (Figure 1). These four surfaces were monitored at four timepoints: a) Pre-treatment Daytime, b) Pre-treatment Nighttime, c) Post-treatment Daytime, and d) Post-treatment Nighttime (Figure 2). The inclusion of a control surface measured both before and after treatment enables the use of the BACI experimental design which allows for changes in thermal surface temperatures to be directly attributed to changes in the road surface.

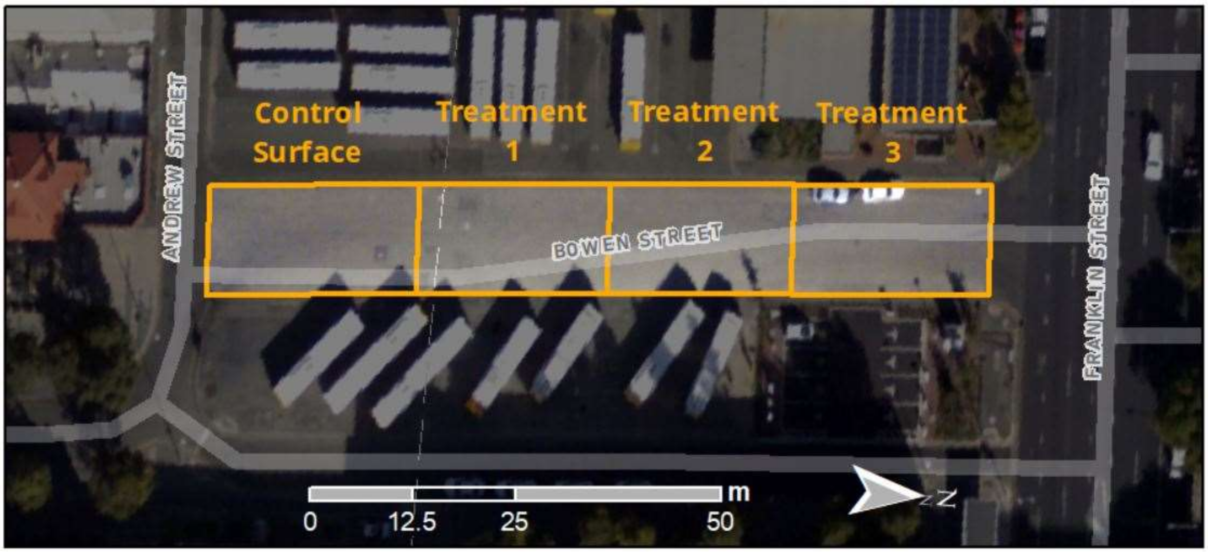

Figure 1. Aerial map of the control and treatments.

Figure 2. Illustrative representation of the four datasets collected at various time points that enabled the BACI experimental design. Orange boxes represent the treatment areas.

2.2 Weather conditions

Pre-treatment data collection occurred from 12 am to 1 pm and from 10 pm to 11 pm on the 18th of December 2019. The maximum temperature on this day recorded at the nearest weather station (West Terrace/ Ngayirdapira) was 43.7°C, which followed 42.1°C on the preceding day with an overnight low of 28.6°C. On the 23rd of February 2020 when the post-treatment data was collected, the maximum temperature reached 32.6°C while the overnight low was 13.7°C. Ideally, data would have been collected on a day with higher temperature, however, the summer had notably cooled by mid-February and the day was selected to ensure data was collected before summer finished.

2.3 Analysis

From the 1,988 images collected over the four time points, only images that fell completely within individual target surfaces were analysed. Within each individual image, a target area of approximately 2 m^2 was analysed capturing between 50,000 and 150,000 pixels within each image. This area of analysis began approximately 20 cm behind the observation vehicle's shadow and included areas up to 30 cm from the image boundary to exclude any boundary artifacts and vignetting effect. Images were analysed using FLIR™ thermography software.

Images were categorised according to the target surface area they covered (C, T1, T2, T3, multiple, or none). From each suitable image, values for the central pixels were extracted and averaged to determine the mean absolute surface temperature value for each target area.

Within each timepoint, the mean absolute surface temperature values (Abs) for each of the treatment areas (T1-T3) were converted to relative temperatures (Rel) by subtracting the temperature of the control surface at the same time (C) providing a relative temperature value (Equation 1). This process was repeated for all pre-treatment surfaces for daytime and night time datasets to generate relative temperatures using the control surface (C) temperature acquired at the same time.

$$\mathrm{T1}_{\mathrm{preAM}}\mathrm{Abs} \quad - \quad \mathrm{C}_{\mathrm{preAM}}\mathrm{Abs} \quad = \quad \mathrm{T1}_{\mathrm{preAM}}\mathit{Rel}$$

Equation 1. Control equation for converting from absolute temperatures to relative temperatures. Example uses the T1 surface before treatment. The same equation is applied to all pre-treatment surfaces.

To control for inherent variability along Bowen Street prior to the treatment applications, the pre-treatment relative temperature values were used as a correction factor for each target surface area to ensure that results were not reflecting patterns already present in pre-treatment conditions. The pre-treatment relative temperature for each surface was subtracted from the post-treatment absolute temperature value to calculate the corrected (Cor) absolute surface temperature (Equation 2).

$$\mathrm{T1}_{\mathrm{postAM}}\mathit{Abs} \quad - \quad \mathrm{T1}_{\mathrm{preAM}}\mathit{Rel} \quad = \quad \mathrm{T1}_{\mathrm{postAM}}\mathit{Cor}$$

Equation 2. Control equation for correcting the post-treatment temperatures for any inherent temperature variation present prior to treatment.

The post-treatment corrected absolute temperature value (Cor) for each treatment surface was then subtracted from the post-treatment control temperature value (C, Abs) to calculate the impact value (Imp) of the treatment application (Equation 3). Utilizing this dually controlled BACI experimental design, this process results in values that measure the amount of surface cooling directly attributable to the application of each surface treatment type.

$$\mathrm{C}_{\mathrm{postAM}}\mathit{Abs} \quad - \quad \mathrm{T1}_{\mathrm{postAM}}\mathit{Cor} \quad = \quad \mathrm{T1}_{\mathrm{AM}}\mathit{Imp}$$

Equation 3. Control equation for comparing pre- and post-treatment temperatures.

2.4 Results

Surface treatment 3, the northern most treatment area, delivered the greatest amount of cooling during both daytime and nighttime conditions, measuring 8.65°C and 4.24°C cooler than the control surface using the BACI control design (Figure 3, Appendix B). Surface treatment 2, the second most northerly section, delivered the second-best results, delivering a cooling of 4.95°C and 2.90°C during the day and night, respectively. Surface treatment 1, the southern most treatment area, also produced a cooling impact though its magnitude was less than the other two treatments, measuring 2.60°C and 1.46°C of cooling during the day and night respectively.

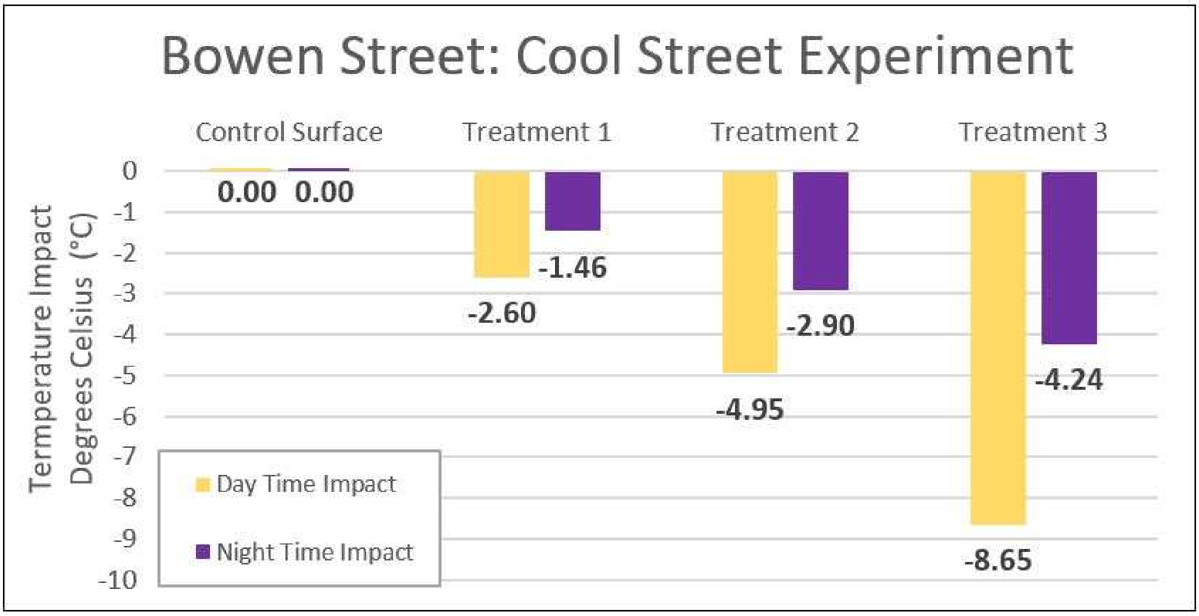

Figure 3. Day and night time cooling impact of surface treatments.

Differences were most visible at the transition zones between surface treatments (Figure 4 and Figure 5) where changes in the surface colour were clearly visible in the thermal data, differentiating between temperatures of as little as 0.1°C. Each transition between treatment types was clearly visible in both the imagery and thermal data, supporting the findings of multiple degree Celsius temperature differences between surfaces.

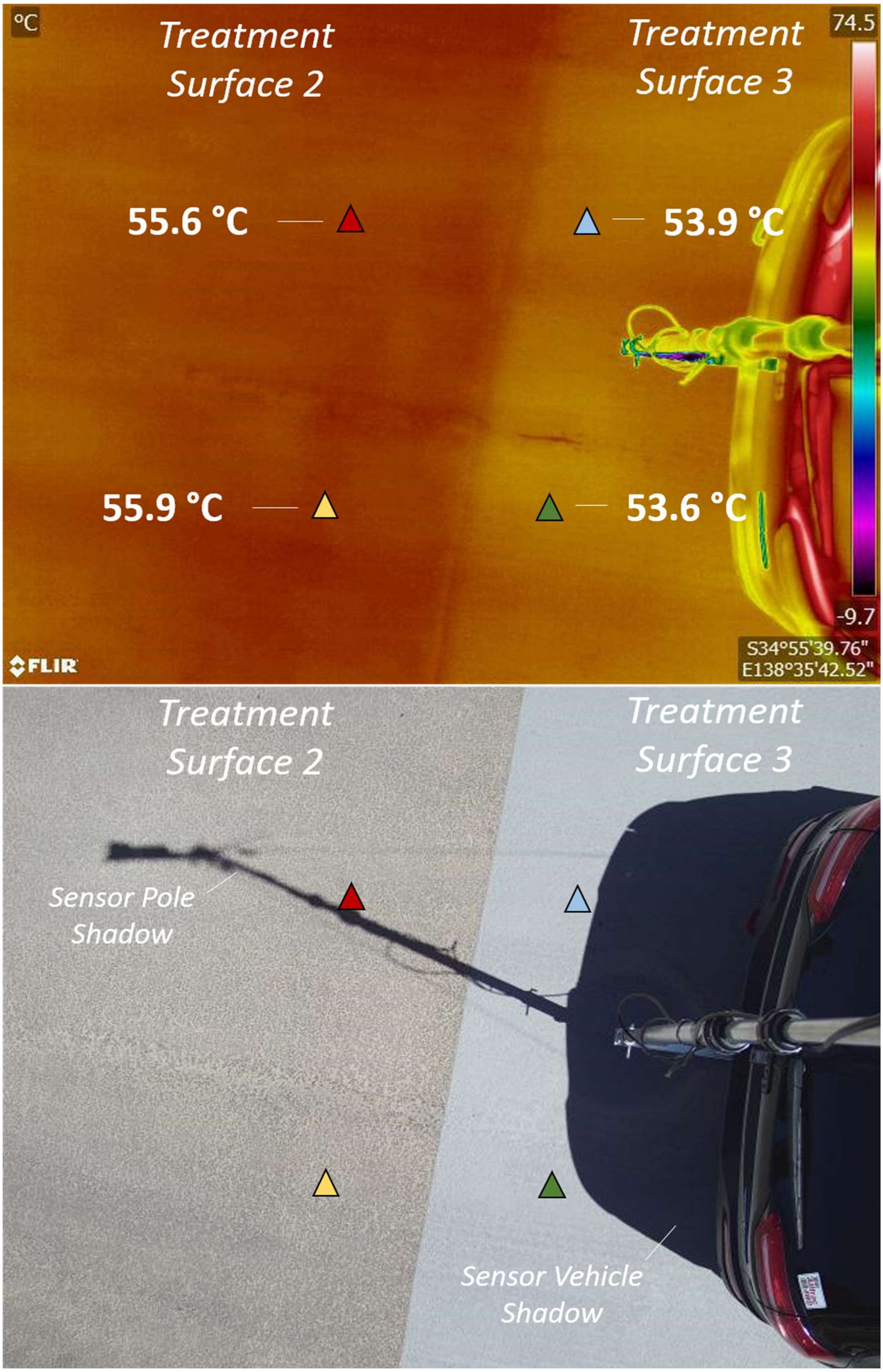

Figure 4. Transition boundary example. North is to the right in the image.

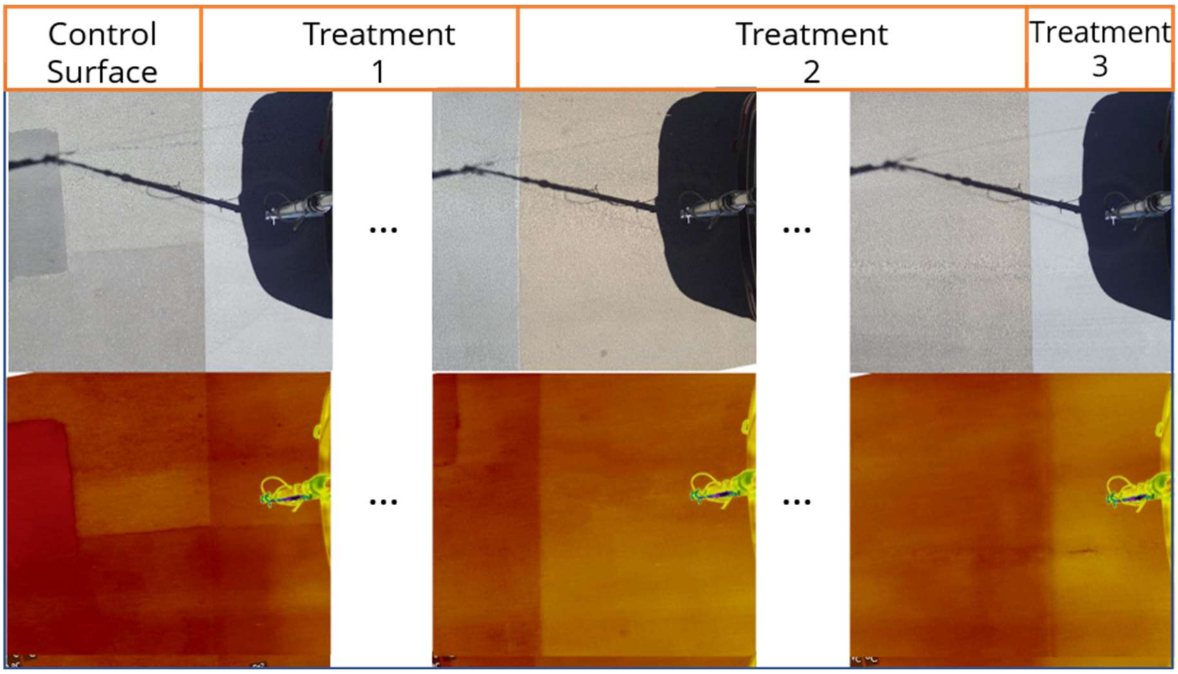

Figure 5. Transition zones between treatment surfaces displayed in colour (top) and thermal (bottom) imagery.

2.5 Discussion

In addition to the temperature differences attributable to the cooling surface treatments, substantial temperature differences were found among various ages, and therefore various darkness, of traditional asphalt surfaces. Fresher, darker asphalt was observed to be upwards of 6°C hotter than older, lighter coloured asphalt (Figure 6). Tar sealant used to cover cracks in asphalt also displayed very high temperatures, measuring almost a full degree °C hotter than even fresh asphalt (Figure 7).

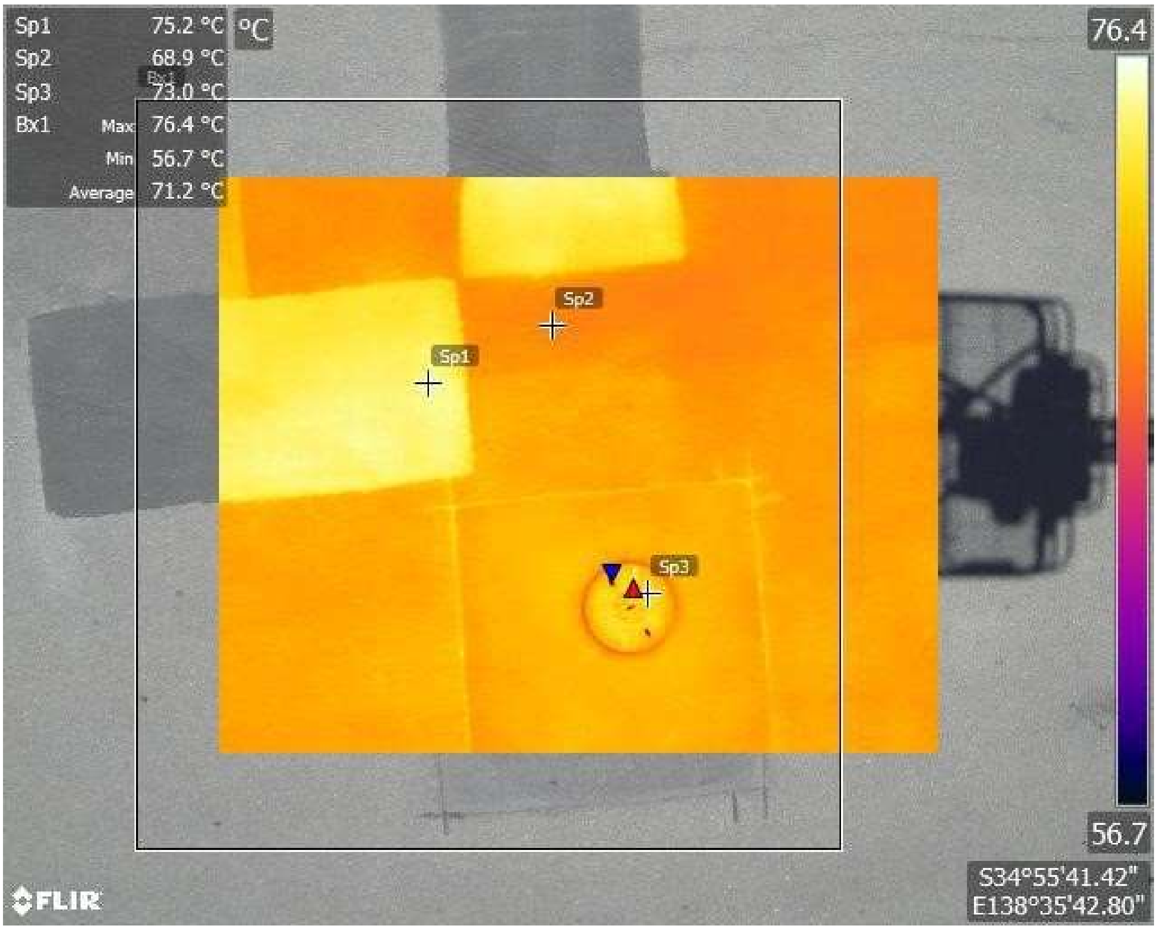

Figure 6. Various temperatures of different asphalt colour.

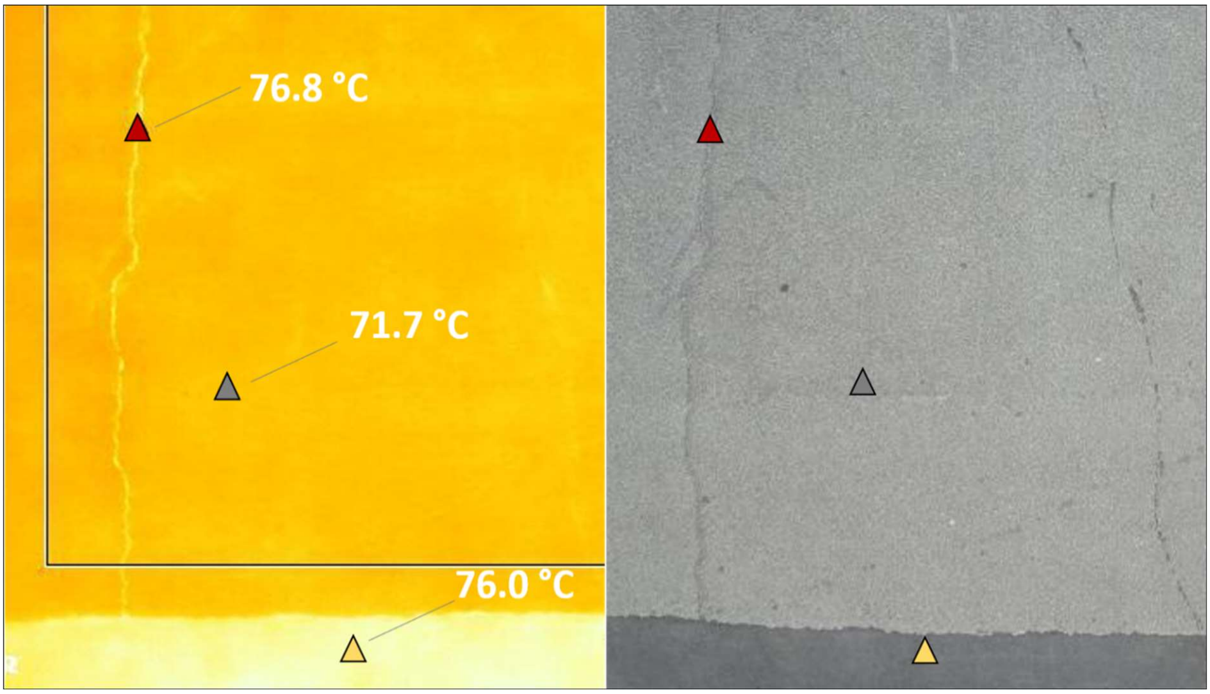

Figure 7. Various temperatures of asphalt.

3 Air column temperature assessment

3.1 Methodology

Bluetooth Hobo Temperature Data Loggers encased in standard shields (Figure 8) recorded the air temperature at 10cm, 100cm, 150cm, 200cm and 250cm above the three cool road sealants and asphalt control site. Smartphones recorded live Bluetooth logger fed data. Phone data capture occurred in 30-minute increments across an 11.5 hour (10:30am – 10:00pm) time period and included day-time and night-time temperatures.

Two 280cm masts (Mast A, Mast B) were each fitted with five data loggers and accompanying shields at the previously stated heights. Mast A recorded air temperatures only above the control site (C). Mast B moved between all three treatment sites (T1, T2, T3) to capture air temperature. Recordings of air temperatures from Mast A were captured at the same time as recordings from Mast B.

Data was recorded at the same location within each treatment area. Masts were held in place by staff and allowed 1 minute of calibration time in each treatment prior to phone data capture. A laser heat gun captured surface temperature across the four surfaces in 30-minute increments across the 11.5 hour recording period.

Estimates of cloud cover and cloud blocking direct sunlight (Appendix C) were recorded at the time of data capture each 30 minutes.

Figure 8. Hobo Temperature Data Loggers enclosed in casing.

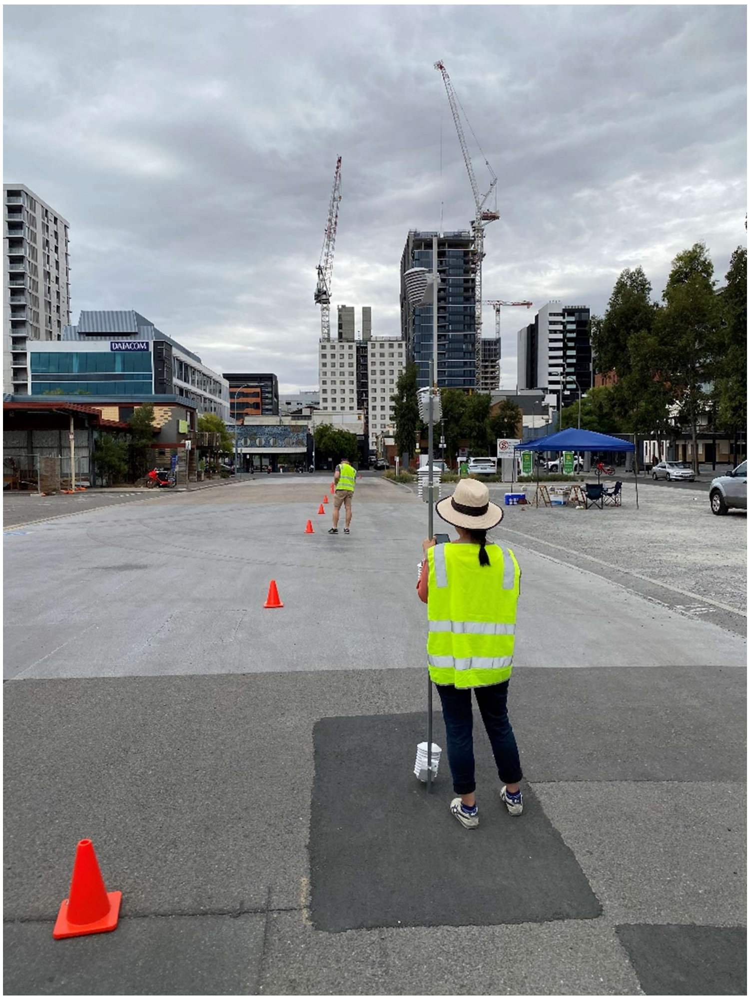

Figure 9. Data Collection at the Bowen Street site.

3.2 Weather conditions

Data collection occurred from 10:30am to 10:00pm on the 18th of March 2020. Bureau of Meteorology data collected from the nearest weather station, Adelaide (West Terrace/ Ngayirdapira), recorded a maximum daily temperature of 34.1 C°, the highest daily maximum for March 2020 (Bureau of Meteorology). Wind speed ranged from 11-13km/h from a NNE, NNW and WNW direction with gusts of up to 39km/h (Bureau of Meteorology 2020). The day was originally identified for sampling because the forecast indicated no cloud cover, however, cloud developed early in the morning and by midafternoon there was near continuous cloud (Appendix C).

3.3 Results

3.3.1 Air temperature

Cool road sealants appeared to have little to no influence in reducing air column temperatures when comparing the control to all three treatments. This was consistent across all recording heights. The data does not indicate a significant difference between the control and the three treatments or the three treatments in comparison to each other. This is consistent across all five recording heights. The control recorded a lesser or equivalent average temperature compared to Treatment 1 at 10 cm, 150 cm, 200 cm and 250 cm recording heights (Appendix D). The average control temperature at 250 cm of 31.87°C, is less than all other treatment average temperatures recorded at the same height (Appendix D).

Average data indicates a correlation between air temperature and height. The highest average temperatures were recorded at 10 cm above the trial surfaces and the coolest average temperature was recorded 250 cm above the trial surfaces (Table 1).

	10 cm	100 cm	150 cm	200 cm	250 cm
Control	32.42	32.29	32.07	32.09	31.87
Treatment 1	32.43	32.14	32.08	32.09	31.97
Treatment 2	32.36	32.13	32.02	32.06	31.94
Treatment 3	32.35	32.22	32.03	32.04	31.92

Table 1. Average air column temperature across the day for the control and treatment sites.

10cm Height

Both the maximum and the minimum recorded temperatures were recorded 10 cm above the pavement surface (Appendix D). The greatest range in temperature was recorded at 10 cm above the pavement surface in the Control (Appendix D).

After sunset (7:30 pm ACST) air temperature at a height of 10cm over the control site was less than or equivalent to air temperatures recorded over all other treatments. Data recorded at 10 cm above the pavement logged higher peak temperatures than other recorded heights (Figure 10), with the magnitude of this difference between 10 cm and 250 cm approximately 0.3 to 0.4°C.

100 cm, 150 cm, 200 cm, 250 cm

Data from the 100 – 250 cm range indicated that the air closer to the surface was on average slightly warmer than air further from the surface (Appendix D). The spread of air temperatures recorded at different times of the day at different heights above the road surface are presented in Figures 11 to Figure 15.

3.3.2 Surface temperature

Surface temperature spot measurements were taken at the same time interval as air temperature measurements using a Stanley Infrared Thermometer. Data was collected from two asphalt patches, the lighter coloured road base and a recently laid dark coloured patch. For the purpose of this report, the data collected from the road base is referred to as Control Site 1 and the data collected from the dark coloured asphalt is referred to as Control Site 2 (Appendix E). The data collected with the thermal gun was much less comprehensive than the data presented in Section 2 and should be considered as indicative only.

Surface temperatures were on average at least more than 5°C higher than average air column temperatures. Surface temperature data (Figure 15) shows that Treatment 2 and Treatment 3 recorded lower temperatures than the two control sites at all times, with the exception of 11:30am. The control recorded lower surface temperature than Treatment 1 at 11:00, 11:30, 12:00, 13:00, 13:30 and 15:00. Notably, the temperature difference between the control and Treatment 3, the most effective treatment at cooling according to the results in Section 2, was around 2 to 3.5°C.

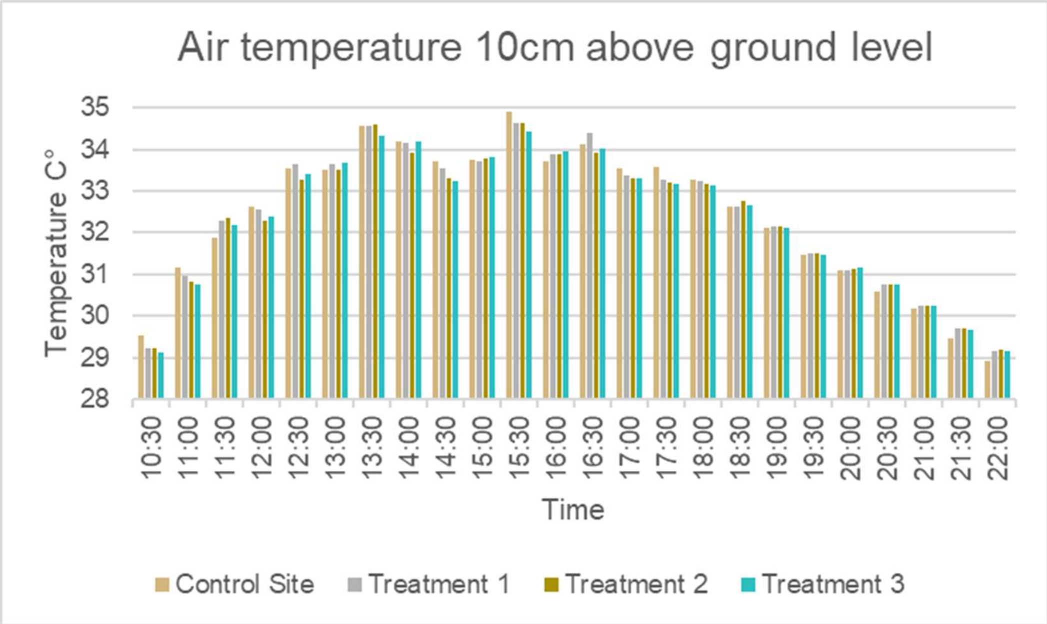

Figure 10. Air column temperature recorded 10cm above the road surface

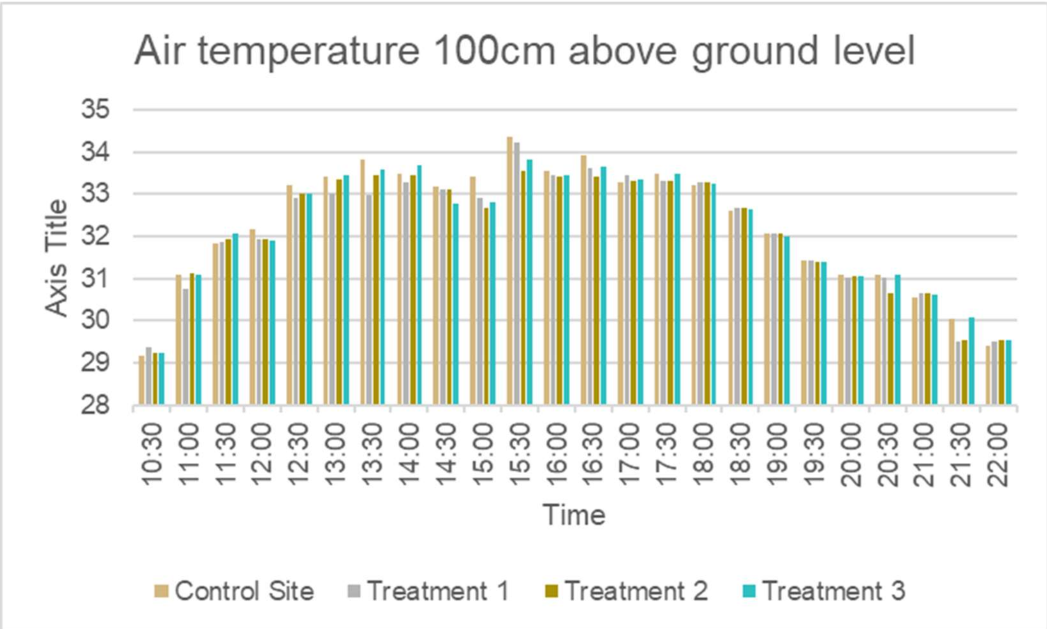

Figure 11. Air column temperature recorded 100cm above the road surface.

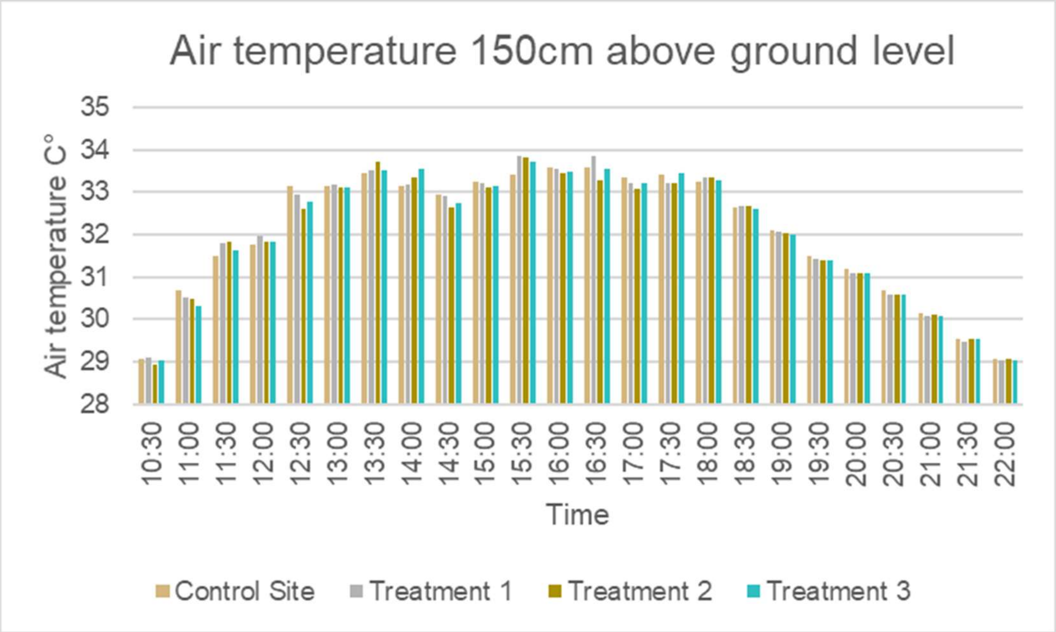

Figure 12. Air column temperature recorded 150cm above the road surface.

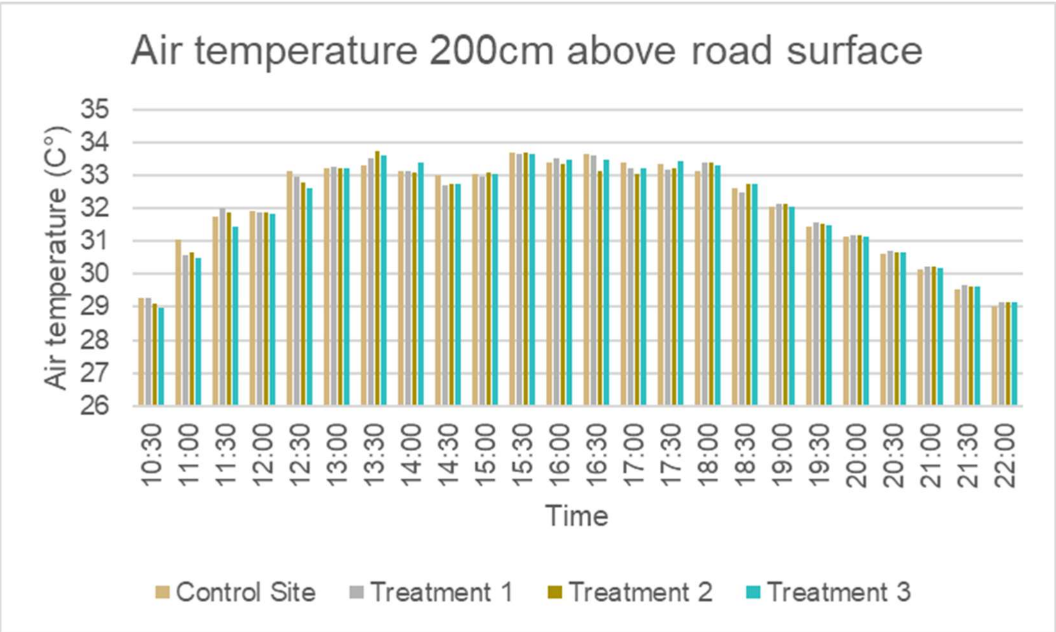

Figure 13. Air column temperature recorded 200cm above the road surface.

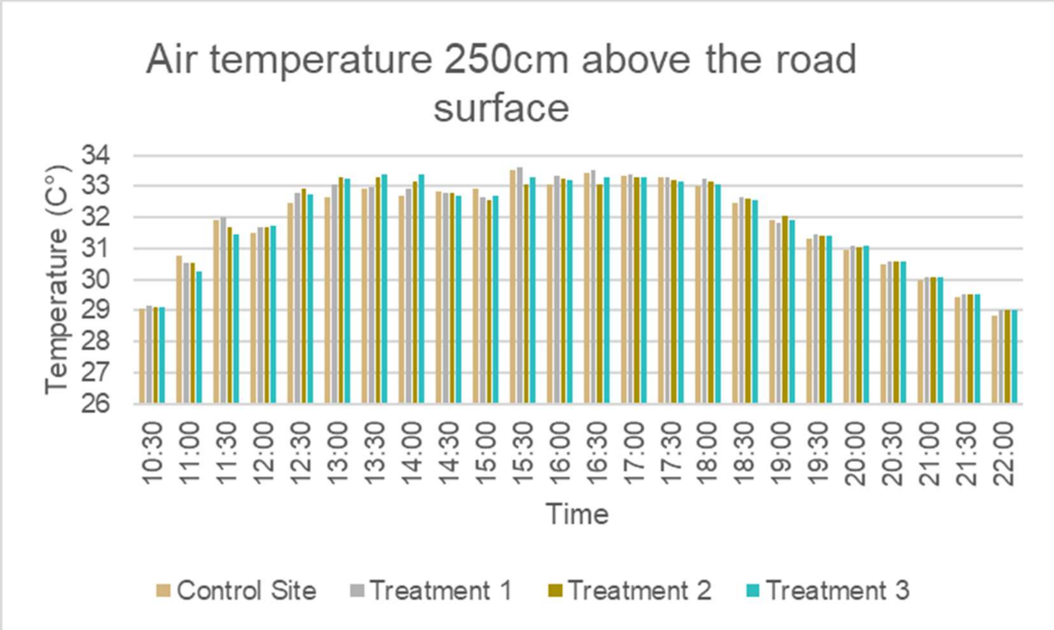

Figure 14. Air column temperature recorded 250 cm above the road surface

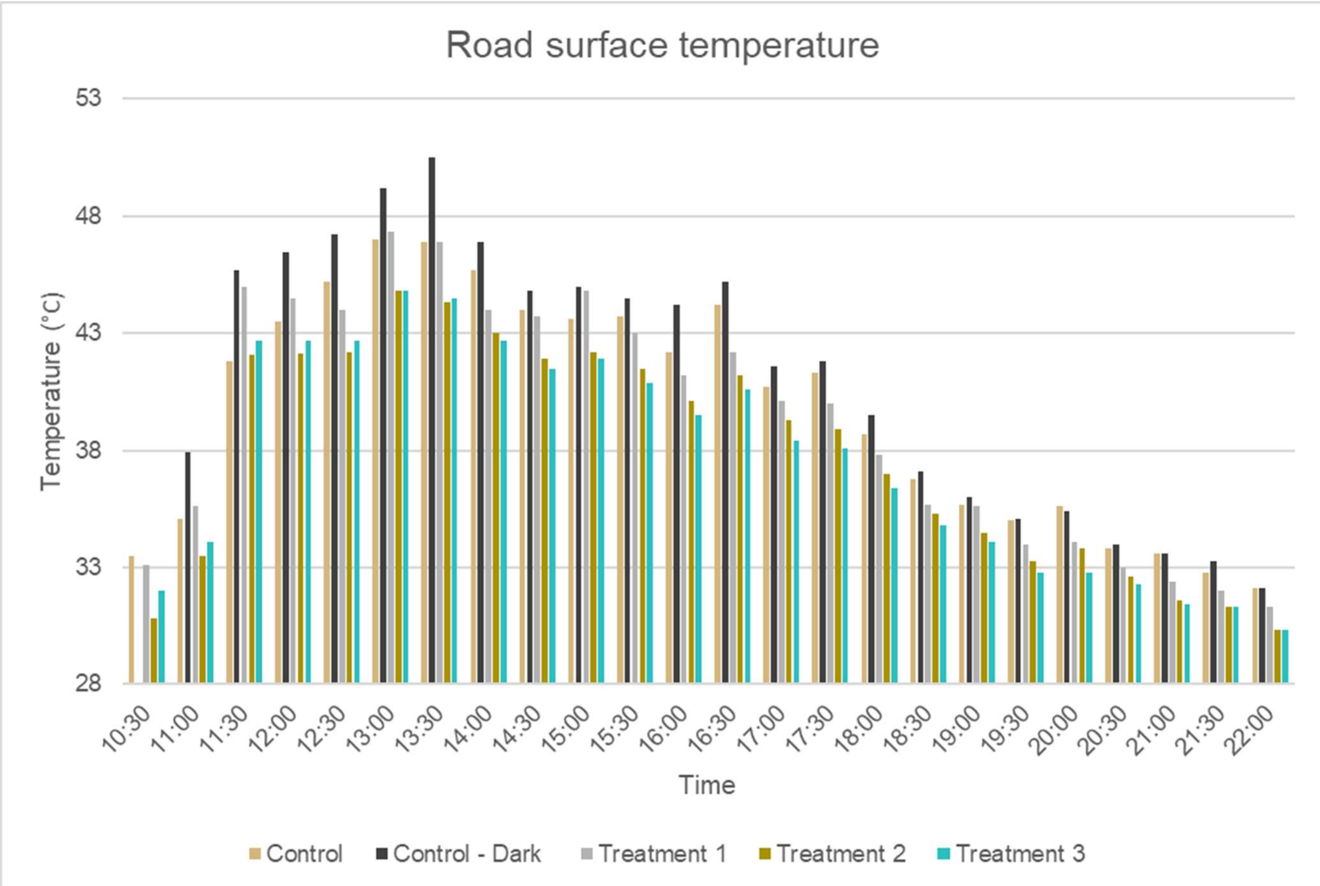

Figure 15. Surface temperature of the three different treatments (T1, T2, T3) and two asphalt control sites.

4 Modelled heat island analysis

4.1 Methodology

To understand the potential impact of widespread application of the cool road sealants tested along Bowen Street, the Water Sensitive Cities Centre for Research Cooperation (WSC CRC) Scenario Tool was engaged to estimate the cooling benefits on surface temperatures and air temperatures.

The Scenario Tool[1] is a planning-support tool that enables users to assess the evolution of urban infrastructure, water networks and population demographics over time. The interactions and influence between these elements are modeled in a Geographic Information System (GIS) based platform. Users can input their own data related to the different systems, or use the available baseline data to simulate different development scenarios. Users can create personalised adaptation planning strategies and test them under dynamic what-if scenarios with a wide variety of stakeholders.

The Scenario Tool has a range of modules that can be used for assessing development scenarios. For the purpose of this analysis, the following modules of the Scenario Tool were applied:

- “Extreme Heat Day” Land Surface Temperature Module, which enables users to assess the spatial distribution of “Extreme Heat Day” land surface temperature for a given site.

- The Air-temperature Response to Green/Blue infrastructure Evaluation Tool (TARGET) Module, which enables users to assess land surface temperature, air temperature and human thermal comfort for a given site.

The Land Surface Temperature module within the scenario modeling tool is based on a land cover analysis that categorizes the land surface into seven land covers (tree, water, dry grass, irrigated grass, roof, road, and concrete). Each cover type has a corresponding land surface temperature as identified during a 2012 Melbourne study (Table 2). The composition of the target area is defined by the proportion of land that falls within each category, and these proportions of each land cover type are multiplied by the corresponding temperature to model the overall average surface temperature. By changing the proportion of land covers through various scenarios, the change in overall average surface temperature reveals the impact of those changes.

Land cover	Pixel value	Temperature (80^{th} percentile)
Tree	1	38.5
Water	2	30.2
Dry grass	5	58.9
Irrigated grass	7	37.5
Rood	12	62
Road	13	57.4
Concrete	15	49.8

Table 2. Land surface temperature reference table for the Scenario Tool.

[1] https://watersensitivecities.org.au/wp-content/uploads/2020/04/200420_V5_Water-Sensitive-Cities-Scenario-Tool.pdf

4.1.1 Data

The area of analysis was restricted to the urban-only area within the City of Adelaide boundary. This excludes all of the major parklands but includes internal parks such as Victoria Square Tarntanyangga. The urban-only area equated to 6.56 km^2 (Figure 16).

Roads were extracted from the Department of Planning, Transport and Infrastructure (DPTI) roads database acquired from www.data.sa.gov.au. Only significant thoroughfare roads[2] were included in the analysis as these represent the largest and most exposed road surfaces, whereas narrower roads and laneways[3] often experience substantial shading from adjacent buildings and, particularly in the Adelaide CBD, are mostly north-south oriented further limiting exposure to the sun. The road length equated to 77,716 metres, which includes double counting of separated roads and boulevards.

Road surface areas were initially determined as all areas within 5 m of the selected road centrelines, then were manually expanded (street-by-street) to include all bitumen area from kerb to kerb, including parking spots, bike lanes, etc. that were contiguous with the road surface. Major road area within the urban area equated to 0.956 square kilometres, or 14. 6% of the total urban area.

The datasets used in the modeling analysis were, 1) Adelaide Urban Boundary (Urban Area), and 2) Adelaide Major Urban Road Area (Road Area).

4.1.2 Assumptions

The following assumptions were made in applying the Scenario Tool:

- Only designated major roads were included. These equate to approximately 1200 of 2200 (60%) road segments in the DPTI database, but likely encapsulate ~80% of road area due to smaller roads and laneways being narrower.
- Specific road area boundaries were interpreted from aerial imagery captured during March 2018.
- The land cover data included within the tool estimated 13% road coverage within the urban boundary, roughly consistent with the road area dataset, with differences attributed to the coarser scale of the land cover analysis.
- The Scenario Tool is predicated on the above reference table (Table 2) of land surface temperatures as acquired during a 2012 Melbourne study. Although the absolute temperatures are used in the model, the comparative relative differences in thermal performance (as used in this study) provide direct attributable indications of cooling or warming influence due to land use change.

4.1.3 Analysis:

The standard land cover classification within the CRC Scenario Tool includes *Road* and *Concrete* categories, measuring 57.4°C and 49.8°C, respectively, but does not contain any equivalent *cool road* surfaces. To model the impacts of wide-spread cool road application, the observed cooling results were recreated in the model as a mix of *road* and *concrete* surfaces in various proportions. For example, to replicate the cooling effect of Treatment 1 (2.60°C below the control road temperature, or equivalent to 54.8°C within the model), a mix of 65.9% road and 34.1% concrete was modeled which generated the 2.6°C of cooling (Table 3). Treatment 3, however, was below the temperature of concrete so a fraction of irrigated grass was added to simulate that surface.

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[2] Selected roads include all DPTI roads classified as "*Suba", "Art", or "Coll".*

[3] Excluded roads include all DPTI roads classified as "Locl".

Figure 16. Map showing the urban roads and area included in the Scenarion Tool modeling analysis.

CRC Surface	Proportion of "Road"	Proportion of "Concrete"	Proportion of "Irrigated Grass"	Modelled Surface Temp (°C)	Modelled Temp Relative to "Road" (°C)
T1	0.659	0.341	-	54.81	-2.60
T2	0.351	0.649	-	52.46	-4.95
T3	-	0.917	0.083	48.76	-8.65
Road	*1*	-	-	57.41	0
Concrete	-	1	-	49.78	-7.63
Irrigated grass	-	-	1	37.45	-19.96

Table 3. Surfaces reference table with surface proportions used to synthesise cool road sealant impacts.

The Scenario Tool was applied using the urban area only (i.e. excluding all major parklands but including internal parks). The road areas dataset was added to the model and those areas were assigned a "road" classification equivalent to 57.4°C surface temperature, using the "assign fractions" workflow node in the Scenario Tool. This combined urban area and roads scenario (Asphalt Roads scenario) resulted in an average surface temperature of 55.3°C (

Table 4). An example of the CRC Scenario Tool land surface temperature estimation for Adelaide under the Treatment 1 scenario is provided in Figure 17 to demonstrate the outputs of the tool.

The Treatment 3 scenario applied the 8.7°C surface cooling effect measured at the Bowen Street test site to the Adelaide urban road area (14.6% of the total urban area). Treatment 3 generated a city-wide surface cooling of 0.9°C. The Treatment 2 scenario, modeling the cooling impact of 5.0°C road temperature reduction, resulted in a city-wide surface cooling of 0.4°C. The Treatment 1 scenario, which had a 2.6°C lower than control surface temperature, generated a city-wide surface temperature reduction of 0.04°C. These are the city-wide cooling benefits specifically attributable to the broad application of the respective surface treatments.

For comparison, adding 10% tree canopy to current City of Adelaide roads with the Asphalt Roads scenario lowered city-wide surface temperature by 0.25°C. Running the model with tree canopy coverage of approximately 33% of the road surface would deliver a surface cooling benefit of 0.82°C, similar to Treatment 3. This means that a small to moderate increase in tree canopy coverage can have a similar effect to complete road coverage with the products assessed in this study. Importantly, this is based on changes to average surface temperature as a result of including the surface temperature at the top of a tree canopy. Notably, this underestimates the value of trees in reducing human thermal comfort, given that their primary benefit comes from the shade generated which is a function of the tree canopy intercepting incoming solar radiation.

When viewed from above, urban streetscapes consist of a mixture of surface materials of different ages, often covered with materials that are more reflective (and hence cooler) than asphalt, such as painted road markings, overhanging street lights, and most importantly from a temperature consideration, trees. As such, the generic baseline scenario specific to the City of Adelaide which includes these features generated an average surface temperature of 54.5°C, more than 0.8°C cooler than the Asphalt Roads scenario used to determine the cool roads treatment impact.

The TARGET module in the Scenario Tool provided estimates of the potential air temperature benefits of widespread use of cool road sealant across the city and has been primarily designed for assessing the benefits of blue-green infrastructure. This study attempted to use the module for air temperature but it was not able to produce a result at the time of the completion of this report. If a result is determined, the findings will be shared separately.

Surface Treatment Scenario	*Measured Local Surface Cooling Effect (°C)*	*Modelled City-Wide **Surface** Temperature (°C)*	*Modelled City-Wide **Surface** Temperature Impact (°C)*
Asphalt Roads	0.00	55.30	**0.00**
Treatment 1	-2.60	55.26	**-0.04**
Treatment 2	-4.95	54.92	**-0.38**
Treatment 3	-8.65	54.40	**-0.90**

Table 4. Results table showing mean modelled results of city-wide application of cool road sealants.

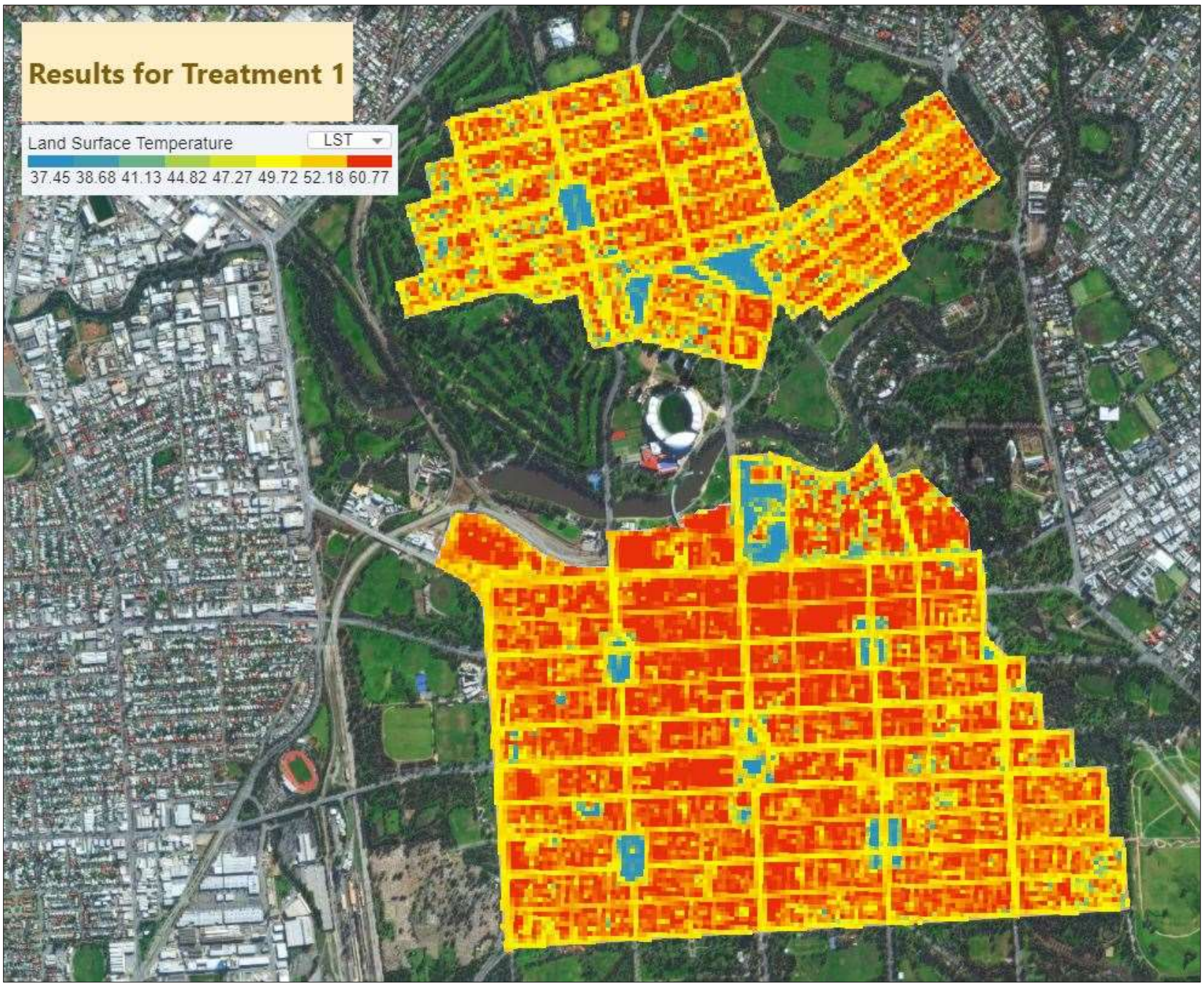

Figure 17. Example of land surface temperature estimation for Adelaide under the Treatment 1 scenario to demonstrate the outputs of the modelling tool.

5 Community stakeholder engagement

5.1 Collection of community feedback

The Cool Road Adelaide Project partners encouraged feedback from the community regarding a number of factors relating to this project. Feedback was sought via two methods. The community were given the opportunity to complete a feedback form on the *Your Say Adelaide* webpage, the City of Adelaide's primary community feedback mechanism. Feedback forms were also made available to the public in hard copy format.

The feedback form listed information about the trial and sought comment in relation to temperature, thermal comfort, behaviour change, benefits or concerns, scale of the treatments and treatment preference.

5.2 Feedback from hard copy surveys

There were 731 visits to the survey page on the Your Say Adelaide website, with only six responses. There were a further six responses received on hard copy forms.

The majority of survey participants (over 83%) responded that they would like to see heat reflective treatments on other streets and in other materials, such as footpaths and walls and roofs. Half of all survey respondents supported the notion that cool road surface products helped to make the local temperature feel cooler. The other half responded they did not know whether they felt that cool road surfaces reduced the local temperature.

One survey respondent commented that the cool road trial had increased the number of customers to their business and that customers were stimulated to ask questions about climate change, due to the cool road trial.

Survey respondents listed Treatment 3, the most northern treatment as the highest preference treatment, followed by Treatment 2. Treatment 1 was the least preferred treatment type (Figure 18).

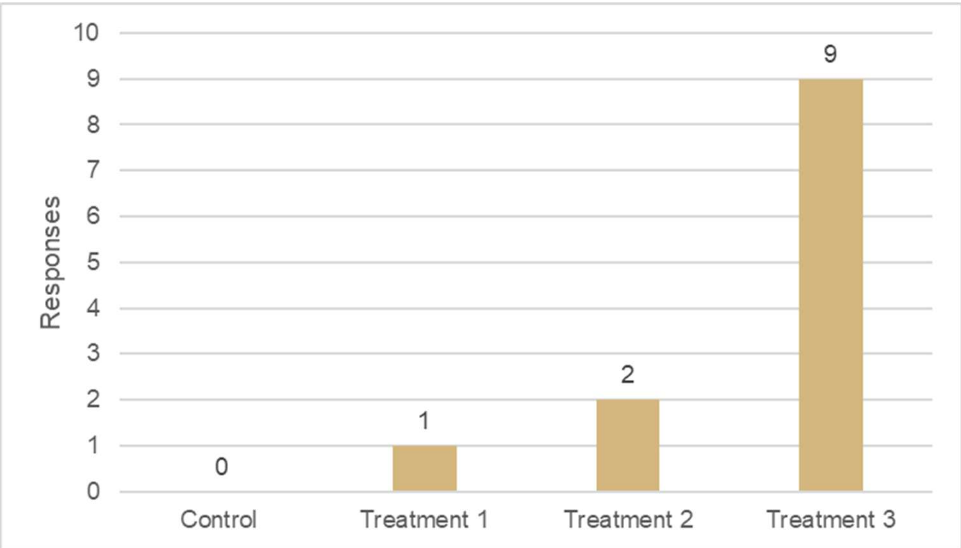

Figure 18. Survey responses regarding which surface type was most preferred.

Responses from the survey respondents who listed Treatment 3 as the preferred surface type, listed the following as reasons why they preferred it to the other treatments:

- Cooler pavement (2 responses)
- "The lighter the better …"

- “Dirty” appearance (this is listed as a positive)
- Smoother feel for skating

One respondent listed Treatment 1 as the preferred treatment as it displayed the least glare.

Responses from surveys indicated that the community were generally pleased with an investment in cool roads as a climate change response. When asked “Do you think we should implement heat reflective roads on other streets?” responses included:

- *“I definitely agree that the dark colour of roads contributes to a large heat trap, however, I believe that a canopy cover of roads is a better outcome. I also think that there is far more roof space than road space across the city, and you can tell the dark roof buildings vs the light roof buildings on the heat map.”*
- *“Yes. The city doesn't have space for street trees on every verge so by having heat reflective road it will cool the city streets. It would make for a more comfortable walk / ride in the city. The Adelaide suburbs have tree lined street which make it very cool to ride on even on hot days. But the city doesn't have as many tree lines street which makes it even hotter on hot days.”*

However, cool roads were recognised as not being a solution for all areas with one response indicating:

- *“Street trees are a proven effective way to achieve cooler streets with the added benefits of shading local properties, providing habitat for other animals, psychological benefits of greenery and carbon sinking.”*

5.3 Social media engagement

Social media interest in posts regarding the cool roads were strong, with good engagement occurring across Facebook, LinkedIn and Twitter. The trial also featured in a Good Living web article[4].

Although no surveys were conducted using these platforms, the engagement level indicates strong interest from social media followers. Examples of feedback are provided in Figure 19 and Figure 20. Key statistics are as follows:

- Facebook
  - Post 1 – reach 9,899/ engagement 1,176/ engagement rate 11.9%
  - Post 2 – reach 3,702/ engagement 93/ engagement rate 2.5%
  - Post 3 (Promoted by the Minister for Environment and Water) achieved the following results:
    - Reach 3,800 accounts
    - Video views: 1,700
    - Most popular with women aged 35-44
    - Reactions: 157
    - Comments: 27
    - Shares: 19
- LinkedIn
  - Impressions - 16,220
  - Clicks - 2,757
  - Click through rate - 0.17

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[4] https://www.environment.sa.gov.au/goodliving/posts/2019/12/adelaide-cool-roads

    - Likes – 7
    - Comments – 7
    - Shares – 12
- Twitter
    - Impressions 2,710
    - Engagement 105
    - Engagement rate 3.8%
- Department for Environment and Water Good Living Blog article
    - 916 unique page visits
    - Average reading time of almost 3mins.

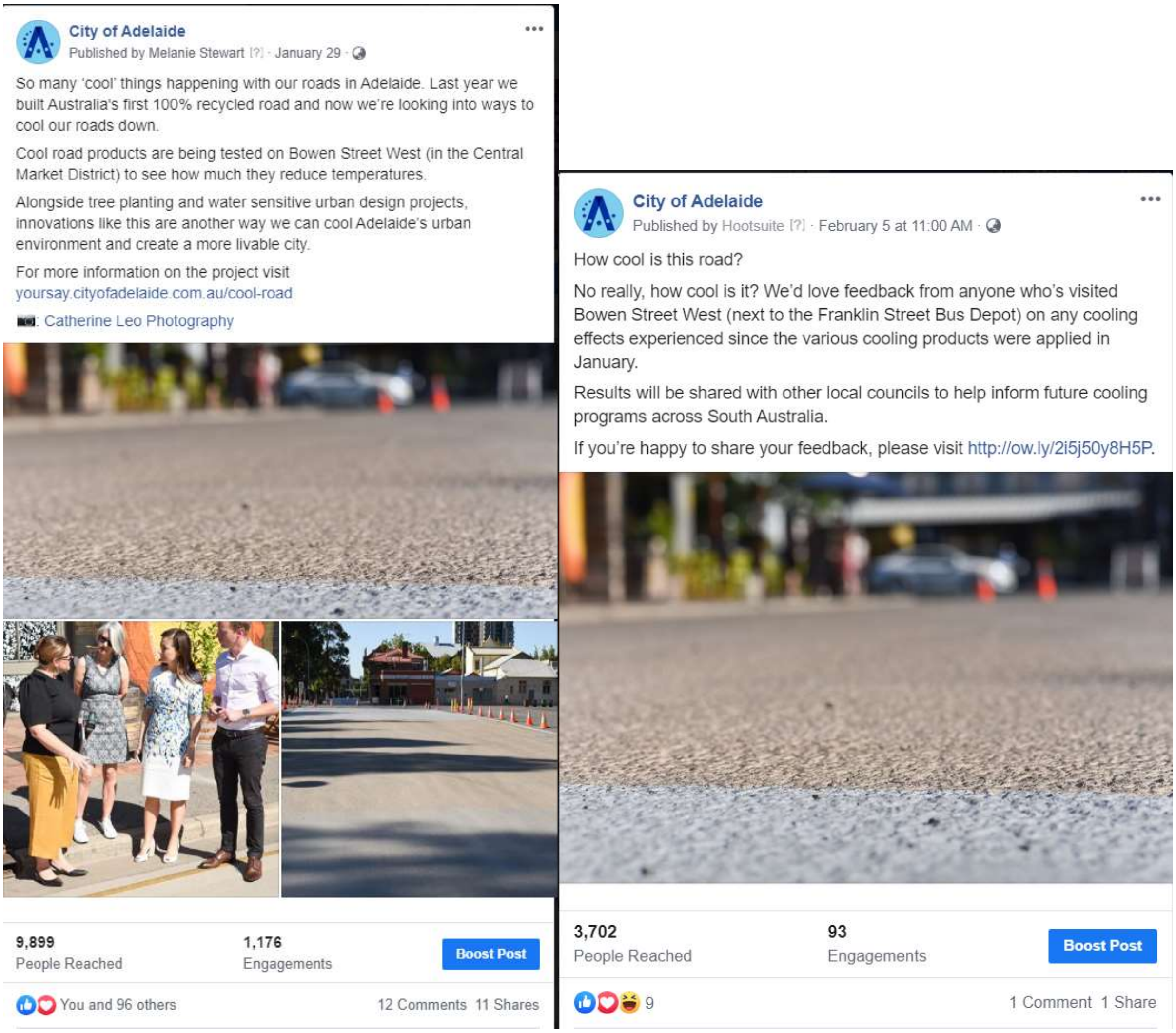

Figure 19. Screen shots of Facebook posts.

Figure 20. Screen shots of LinkedIn posts.

6 Discussion

6.1 Surface temperature

The surface temperature results indicate that cool road sealants can reduce surface temperature when compared with traditional asphalt surfaces, and that new asphalt shows high temperatures than aged asphalt. The extent of cooling achieved by Treatment 3 was greater than for any other surface observed in this study and is higher than recorded for other similar assessments conducted in the City of Salisbury and City of Charles Sturt in the past 1-2 years. However, the average temperature reduction of 8.65°C compared with the control surface was still at the lower end of the advertised range of cool roads, which can reportedly cool the road surface by at least 15°C compared to asphalt.

It is understood that this study provides the first results of any analysis undertaken in Australia of the influence on the road treatments on night time temperature. This indicated that even by 11 pm, well after sunset, the effects of lower temperatures observed during the day were still evident. The relative performance of the treatment also remained the same, suggesting that the rate of cooling was similar. An extension of this analysis would be to continue to determine if the reduction in surface temperature continues throughout the night

Of note is that the relative temperatures of the four surface types remained the same even with the use of the handheld Infrared Thermometer, however, the magnitude of the cooling effect was much lower in the range of 2 to 4°C cooling for treatment 1 on the second occasion. Notably the incoming solar radiation was higher during the first assessment of surface temperature and the first day was near cloudless whereas the cloud cover increased on the second day. This suggest that the results of surface temperature are sensitive to time of year and that a measure of solar reflectance, which is independent of incoming solar radiation, should also be taken in the future. Repeating this analysis during peak times for solar radiation in Adelaide during November to January is likely to yield the strongest results.

Aside from potential heat island mitigation benefits, cool road sealants can help extend the life span of the road surface by reducing temperature related impacts such as spitting and cracking of the pavement which can allow in moisture and lead to deterioration of the surface. Based on these results, temperature reductions should reasonably be expected into the future, however, the lifespan of the surfaces should be monitored through time. This site should prove to be an excellent opportunity to compare the durability of the surfaces given that they will be exposed to approximately the same vehicle traffic over time. Of note is that one of the treatments had already showed signs of colour change between the time of its application and the assessment with the vehicle mounted thermal camera, as evidenced following the removal of a sign that had been adhered to the road surface.

6.2 Air temperature

Air temperature was recorded at five heights above the surface from 10 cm through to 250 cm above the surface. The results clearly indicated that temperatures closer to the ground were higher than at 250 cm, suggesting that the road surface was contributing to heating of the air column, although the magnitude of the difference in temperature was less than 0.5°C. However, the air temperature at 10 cm above the ground surface did not consistently indicate an effect of treatment type across the course of the day.

An inconclusive result regarding air temperature impacts as a result of lower surface temperatures has also been observed in other studies undertaken in Adelaide for cool road sealants. While this may be a real effect, it is also possible that absence of a noticeable effect is because of local wind mixing effects of heat across the air column, the magnitude of the impact being too small to detect or the need to place thermometers closer to the ground surface [5]. Furthermore, the conditions for the air temperature assessment were not ideal for this type of data capture because of the high cloud cover, which would have reduced the amount of solar radiation reaching the road surface and led to lower relative surface temperature differences. As such, this assessment should ideally be repeated during

[5] The shield covering the air temperature sensor prevented measurements being recorded at lower than 10 cm.

the period of November to January on a cloudless day when the incoming solar radiation is at its greatest. These conditions are likely to identify the greatest difference in relative performance of the different road surface types.

6.3 Modelled heat island analysis

The use of the CRC for Water Sensitive Cities Scenario Tool helped to determine the potential benefits of cool road application at a whole of city scale, noting that the roads to which cool road sealants could be applied represent only a subset of all roads in the city (14.6% of the total urban area). The results indicate that widespread use of the most effective sealant could generate a near 1°C cooling in average surface temperature at a whole of city scale. Noting that urban heat islands technically form in areas with a surface temperature 2°C or more above a regional average, this suggests that cool road technologies could help disrupt surface temperature heat islands.

Previous work in Adelaide (Seed Consulting et al. 2018) found areas with mixed thermal landscapes (i.e. hot-spots mixed with cool-spots) had fewer heat islands even when they had higher average surface temperatures. A network of cool roads distributed across the CBD that reduces surface temperatures by 2.6°C to 8.7°C would interrupt the typical hot road-hot roof-hot road pattern of urban centres and could disrupt the accumulation of heat that leads to surface temperature induced urban heat islands.

6.4 Stakeholder engagement

The strong response to the social media posts from across Facebook, LinkedIn and Twitter suggest that there is widespread interest in cool roads across the community. However, and potentially because the technology is new and the community is yet to form an opinion, the number of responses to the hard copy and online survey was low. Despite this, support for the approach was strong in the surveys with support for it to be applied at other locations. However, there was also recognition that trees are also effective in reducing temperatures on and near roads and as such future communications regarding similar projects should consider more fully outlining the cooling benefits of trees versus cool roads and explain why in some instances cool roads may be the only (or preferred) solution for localised cooling.

6.5 Implications for city planning and design

The results of this project have broader implications for city planning and design, both in terms of material section and the role of built versus green infrastructure. In this regard, cool road sealants are themselves not a panacea for urban heat, but should instead be considered as one potential tool for contributing to cooler urban landscapes. Combined with the cooling benefits of street trees, targeted irrigation, and other cooling strategies, cool roads would reduce heat generally and the most extreme urban heat temperatures during future heat waves.

As a general guide, cool roads should not be considered as a replacement for street trees as urban cooling measures. This is because the benefits of street trees in improving human thermal comfort comes primarily through the tree canopy intercepting incoming solar radiation, meaning that the thermal comfort in the shade is more favorable than in direct sunlight. Cool roads provide no such protection against incoming solar radiation because they only alter the temperature of the land (road) surface. As such, cool roads will be most suitable as a cooling measure where street trees are not an option (e.g. industrial regions, roads with a narrow verge and footpaths, carparking, awnings, above and below ground services) or where street trees are yet to establish and will take multiple decades to reach maturity.

While not a direct focus of this study, the results also point to the importance of considering roofs in managing surface temperature heat islands in the city. For example, the dominant driver of urban surface temperatures in the Scenario Tool (Section 4) was the presence of roofs, which were the hottest surface type in the modelling environment. Forty seven percent of Adelaide’s urban area is covered by roofs according to the land cover classification. This suggests that a focus on roofs as well as roads should be considered when exploring how the appropriate selection of materials in the built environment can influence the development of heat islands.

6.6 Other considerations

A key consideration in the business case for whether to apply cool road technologies at a larger scale is their durability. The City of Adelaide undertook an assessment of the three treatments approximately 6 months after they were installed. They observed that the full seal coating of the surfaces was still present, however, the sealants had begun polishing off the top of the stone aggregate for the existing oxidised asphalt surface. It was also observed that the visual appearance was better when the product was applied onto new asphalt.

An important consideration in understanding the role of cool roads is their purpose from a road preservation perspective. Part of the intention as a sealant is to reduce moisture penetration into the road base, which can lead to deterioration of the road. It has been suggested that this could result in less soil moisture for street trees in the nearby verge, by as far is understood from the research conducted in this project, this has not been tested in the field. The extent to which this is an issue would be influenced by whether tree roots gain moisture from within the road base and if not, how much moisture would normally move through the road base into deeper soil zones.

An additional concern that has been identified for cool roads is the potential for reflection from the road surface to increase temperature in close vicinity to the road. This may be a significant issue in built up environments where reflected heat can be absorbed by nearby buildings and other types of built form. Research into this issue has suggested that policy makers should weigh up the benefits and local energy use implications of reflective pavements for each site to ensure their optimal application (e.g. Yaghoobian & Kleissl, 2012).This means that the use of cool road sealants may need to be targeted to avoid such areas until a better understanding of the relationship between this type of treatment and heating the nearby built environment is understood.

6.7 Future trials

Further trials of cool road products are essential to test the temperature impacts of cool roads under different conditions and to assess the durability of the surface through time. Considering a broader range of potential sealant types may also prove important if this technology is to be used more widely, noting that the current products are believed to be most applicable to low traffic volume streets. In contrast to the 3 products currently available in Australia there are 13 cool road sealants available on the market in the United States, including some for moderate and heavy traffic flow areas. These warrant further investigation for trial in South Australia, potentially in collaboration with other Metropolitan Adelaide councils. In addition to sealants, other cool road options such as concrete and asphalt with high albedo aggregate could also be tested, which may have reduced flow on impacts such as reductions in soil moisture.

References

Bureau of Meteorology (2020). Adelaide (West Terrace / Ngayirdapira), South Australia April 2020 Daily Weather Observations, Accessed 1 May 2020, Available online:

http://www.bom.gov.au/climate/dwo/202004/html/IDCJDW5081.202004.shtml

Bureau of Meteorology (2020). Adelaide (West Terrace / Ngayirdapira), South Australia April 2020 Daily Weather Observations, Accessed 5 July 2020, Available online:

http://www.bom.gov.au/climate/dwo/202004/html/IDCJDW5081.202004.shtml

Bureau of Meteorology and CSIRO (2018). *State of the Climate*, accessed 4th May 202, available online: http://www.bom.gov.au/state-of-the-climate/

City of Adelaide 2016 – 2020 Strategic Plan, Accessed 1st May 2020, Available online: https://d31atr86jnqrq2.cloudfront.net/docs/strategy-strategic-plan-landscape.pdf?mtime=20190509094049

Green R.H. (1979). Sampling design and statistical methods for environmental biologist. Wiley Interscience, Chichester, UK.

Yaghoobian, N. and Kleissl, J. (2012). Effect of reflective pavements on building energy use. Urban Climate. Volume 2, Pages 25-42. https://doi.org/10.1016/j.uclim.2012.09.002

Seed Consulting Services, EnDev Geographic and Monash University (2018). Collaborative Heat Mapping for Eastern and Northern Adelaide Report. Prepared for the City of Unley on behalf of the Eastern Region Alliance of Councils and the City of Salisbury.

United States Environmental Protection Agency (2005). *Reducing urban heat islands: Compendium of strategies.* Environmental Protection Agency.

Appendix A - Vignetting sensitivity analysis

Analysis of each image focused on only the centre 1/3rd of pixels due to a known vignetting issue with the FLIR camera, whereby pixels further away from nadir (centre of the scene) display an artificial cooling signal. This systematic issue was consistent throughout data collection and therefore does not affect results. A sensitivity analysis of the vignetting issue estimates the effect as limited to 0.2°C for the centre 1/3rd of pixels (Figure 21, Bx 1), and the effect increases to 0.7 C when using the entire image (Figure 21, Bx 3), therefore the consistent analysis method applied here removes that bias and generates a robust repeatable result.

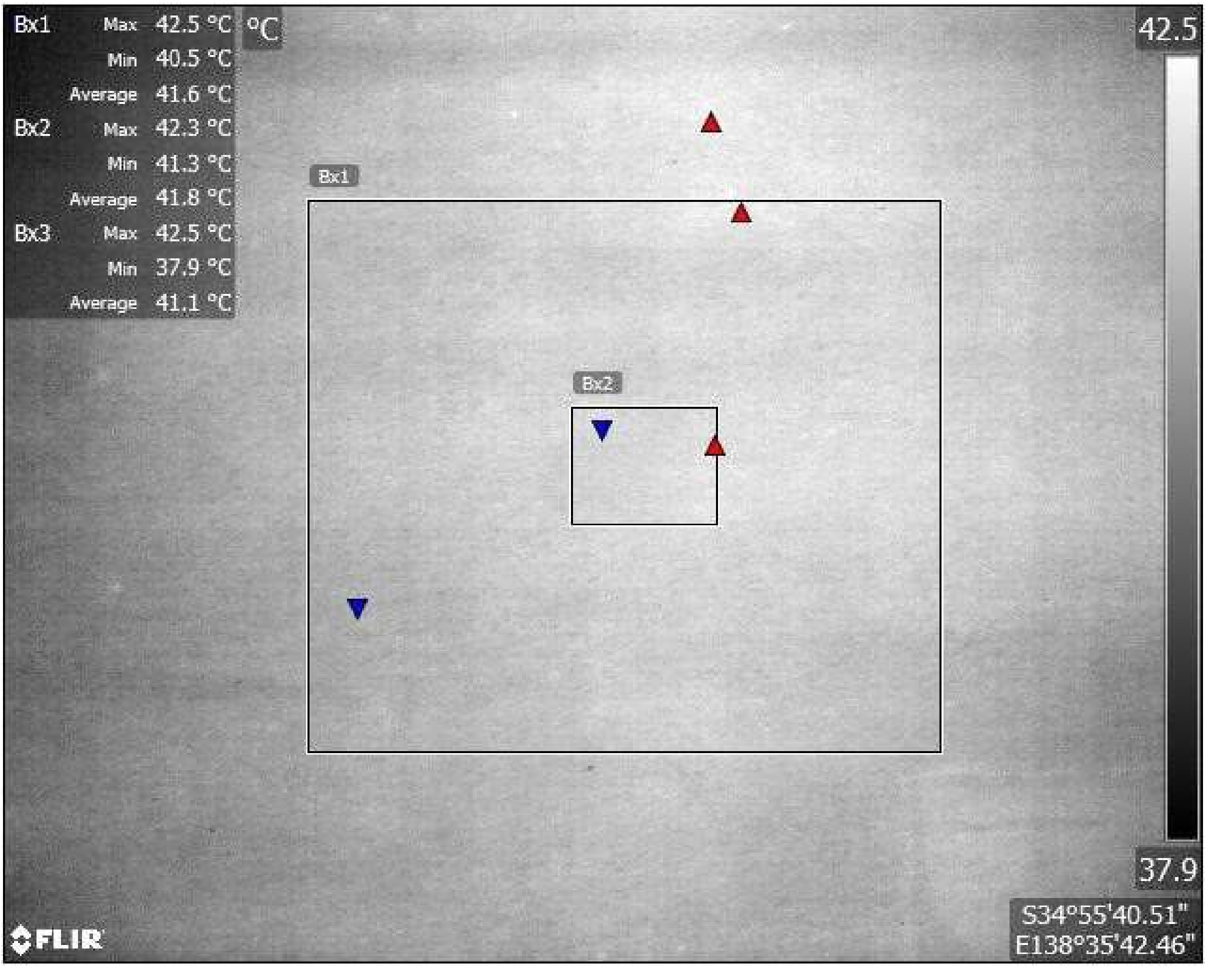

Figure 21. Vignetting sensitivity analysis for FLIR thermographic imager.

Appendix B – Surface temperature

Results table showing mean measured values for each surface at each timepoint and calculated values as described by equations 1-3. All values represent surface temperatures and are given in degrees Celsius Temp (°C).

	Target Surface	Pixels Analysed	Absolute **(Abs)** Temp (°C)	Relative (**Rel**) Temp (°C)	Corrected **(Cor)** Absolute Temp (°C)	Impact **(Imp)** Temp Value (°C)
Pre-AM	C preAM	524,311	71.15	**0.00**		
	T1 preAM	687,931	71.57	**0.42**		
	T2 preAM	437,271	71.17	**0.02**		
	T3 preAM	629,045	72.79	**1.64**		
Post-AM	C postAM	977,947	59.13	**0.00**	59.13	**0.00**
	T1 postAM	919,613	56.95	**-2.18**	56.53	**-2.60**
	T2 postAM	1,051,083	54.21	**-4.93**	54.19	**-4.95**
	T3 postAM	1,051,722	52.13	**-7.01**	50.48	**-8.65**
Pre-PM	C prePM	1,062,380	42.32	**0.00**		
	T1 prePM	855,351	41.86	**-0.47**		
	T2 prePM	692,948	41.18	**-1.14**		
	T3 prePM	821,941	41.74	**-0.58**		
Post-PM	C postPM	736,532	36.61	**0.00**	36.61	**0.00**
	T1 postPM	572,539	34.68	**-1.93**	35.15	**-1.46**
	T2 postPM	733,434	32.56	**-4.04**	33.70	**-2.90**
	T3 postPM	775,054	31.79	**-4.82**	32.37	**-4.24**

Appendix C – Weather conditions

Estimated percentage cloud cover and recording of direct sunlight on the trial area.

Date	Time	Estimated percentage cloud cover	Direct sunlight on the trial area (Yes/No)
18-Mar-20	10:30	50%	Yes
18-Mar-20	11:00	40%	Yes
18-Mar-20	11:30	40%	Yes
18-Mar-20	12:00	50%	No
18-Mar-20	12:30	50%	Yes
18-Mar-20	13:00	40%	Yes
18-Mar-20	13:30	50%	No
18-Mar-20	14:00	70%	No
18-Mar-20	14:30	80%	No
18-Mar-20	15:00	70%	Yes
18-Mar-20	15:30	90%	No
18-Mar-20	16:00	100%	No
18-Mar-20	16:30	100%	No
18-Mar-20	17:00	90%	No
18-Mar-20	17:30	90%	No
18-Mar-20	18:00	90%	No
18-Mar-20	18:30	100%	No
18-Mar-20	19:00	100%	No
18-Mar-20	19:30	100%	N/A (sunset)
18-Mar-20	20:00	100%	N/A
18-Mar-20	20:30	100%	N/A
18-Mar-20	21:00	90%	N/A
18-Mar-20	21:30	90%	N/A
18-Mar-20	22:00	90%	N/A

Appendix D - Air column temperature

The following tables present the air column temperature at different heights above the trial road surface. Data were collected on 18 Match 2020.

		10 cm above ground level			
		Temperature (C°)			
Date	Time	Control Site	Treatment 1	Treatment 2	Treatment 3
18-Mar-20	10:30	29.54	29.21	29.21	29.11
18-Mar-20	11:00	31.18	30.95	30.82	30.75
18-Mar-20	11:30	31.87	32.28	32.36	32.2
18-Mar-20	12:00	32.61	32.56	32.3	32.38
18-Mar-20	12:30	33.55	33.63	33.26	33.42
18-Mar-20	13:00	33.5	33.65	33.52	33.68
18-Mar-20	13:30	34.55	34.57	34.6	34.31
18-Mar-20	14:00	34.18	34.15	33.91	34.2
18-Mar-20	14:30	33.7	33.55	33.31	33.23
18-Mar-20	15:00	33.76	33.73	33.78	33.81
18-Mar-20	15:30	34.89	34.65	34.65	34.44
18-Mar-20	16:00	33.73	33.89	33.89	33.94
18-Mar-20	16:30	34.12	34.41	33.93	34.01
18-Mar-20	17:00	33.55	33.38	33.31	33.31
18-Mar-20	17:30	33.57	33.28	33.21	33.18
18-Mar-20	18:00	33.28	33.23	33.18	33.13
18-Mar-20	18:30	32.63	32.63	32.76	32.67
18-Mar-20	19:00	32.12	32.15	32.15	32.12
18-Mar-20	19:30	31.48	31.51	31.51	31.48
18-Mar-20	20:00	31.08	31.08	31.13	31.18
18-Mar-20	20:30	30.6	30.75	30.77	30.75
18-Mar-20	21:00	30.19	30.24	30.26	30.24
18-Mar-20	21:30	29.46	29.71	29.71	29.66
18-Mar-20	22:00	28.92	29.16	29.18	29.16
Average		32.42	32.43	32.36	32.35
Max		34.89	34.65	34.65	34.44
Min		28.92	29.16	29.18	29.11
Range		5.97	5.49	5.47	5.33

		100 cm above ground level			
		Temperature (C°)			
Date	**Time**	**Control Site**	**Treatment 1**	**Treatment 2**	**Treatment 3**
18-Mar-20	10:30	29.16	29.36	29.24	29.24
18-Mar-20	11:00	31.1	30.77	31.13	31.08
18-Mar-20	11:30	31.84	31.87	31.92	32.07
18-Mar-20	12:00	32.18	31.92	31.94	31.89
18-Mar-20	12:30	33.23	32.92	33	33
18-Mar-20	13:00	33.42	33	33.37	33.44
18-Mar-20	13:30	33.81	32.98	33.44	33.6
18-Mar-20	14:00	33.5	33.29	33.44	33.7
18-Mar-20	14:30	33.18	33.13	33.11	32.79
18-Mar-20	15:00	33.42	32.92	32.69	32.82
18-Mar-20	15:30	34.36	34.23	33.57	33.84
18-Mar-20	16:00	33.57	33.44	33.42	33.47
18-Mar-20	16:30	33.94	33.62	33.41	33.67
18-Mar-20	17:00	33.28	33.46	33.33	33.36
18-Mar-20	17:30	33.49	33.33	33.33	33.49
18-Mar-20	18:00	33.23	33.28	33.28	33.26
18-Mar-20	18:30	32.61	32.68	32.68	32.66
18-Mar-20	19:00	32.07	32.07	32.07	32.02
18-Mar-20	19:30	31.43	31.43	31.4	31.4
18-Mar-20	20:00	31.08	31.02	31.07	31.07
18-Mar-20	20:30	31.08	31.03	30.64	31.08
18-Mar-20	21:00	30.55	30.65	30.65	30.62
18-Mar-20	21:30	30.04	29.51	29.53	30.09
18-Mar-20	22:00	29.39	29.51	29.54	29.54
Average		32.29	32.14	32.13	32.22
Max.		34.36	34.23	33.57	33.84
Min.		29.16	29.36	29.24	29.24
Range		5.2	4.87	4.33	4.6

		150 cm above ground level			
		Temperature (C°)			
Date	**Time**	**Control Site**	**Treatment 1**	**Treatment 2**	**Treatment 3**
18-Mar-20	10:30	29.07	29.11	28.94	29.04
18-Mar-20	11:00	30.67	30.52	30.47	30.32
18-Mar-20	11:30	31.51	31.79	31.84	31.64
18-Mar-20	12:00	31.77	31.97	31.82	31.82
18-Mar-20	12:30	33.16	32.95	32.61	32.77
18-Mar-20	13:00	33.16	33.18	33.11	33.13
18-Mar-20	13:30	33.44	33.52	33.73	33.52
18-Mar-20	14:00	33.16	33.18	33.37	33.57
18-Mar-20	14:30	32.95	32.9	32.66	32.74
18-Mar-20	15:00	33.26	33.23	33.11	33.16
18-Mar-20	15:30	33.42	33.86	33.81	33.73
18-Mar-20	16:00	33.6	33.55	33.47	33.5
18-Mar-20	16:30	33.6	33.86	33.28	33.57
18-Mar-20	17:00	33.37	33.23	33.07	33.21
18-Mar-20	17:30	33.42	33.21	33.21	33.46
18-Mar-20	18:00	33.26	33.36	33.36	33.28
18-Mar-20	18:30	32.66	32.67	32.67	32.61
18-Mar-20	19:00	32.1	32.07	32.04	31.99
18-Mar-20	19:30	31.51	31.43	31.4	31.38
18-Mar-20	20:00	31.18	31.1	31.1	31.08
18-Mar-20	20:30	30.67	30.6	30.6	30.57
18-Mar-20	21:00	30.14	30.09	30.12	30.09
18-Mar-20	21:30	29.54	29.48	29.54	29.54
18-Mar-20	22:00	29.07	29.02	29.08	29.03
Average		32.07	32.08	32.02	32.03
Max.		33.6	33.86	33.81	33.73
Min.		29.07	29.02	28.94	29.03
Range		4.53	4.84	4.87	4.7

		200 cm above ground level			
		Temperature (C°)			
Date	**Time**	**Control Site**	**Treatment 1**	**Treatment 2**	**Treatment 3**
18-Mar-20	10:30	29.26	29.26	29.09	28.97
18-Mar-20	11:00	31.05	30.6	30.67	30.49
18-Mar-20	11:30	31.77	32	31.87	31.46
18-Mar-20	12:00	31.91	31.89	31.87	31.84
18-Mar-20	12:30	33.16	32.95	32.79	32.61
18-Mar-20	13:00	33.21	33.29	33.23	33.23
18-Mar-20	13:30	33.31	33.52	33.73	33.6
18-Mar-20	14:00	33.13	33.16	33.08	33.42
18-Mar-20	14:30	33.03	32.72	32.74	32.74
18-Mar-20	15:00	33.05	32.98	33.08	33.05
18-Mar-20	15:30	33.7	33.68	33.7	33.65
18-Mar-20	16:00	33.39	33.52	33.34	33.47
18-Mar-20	16:30	33.65	33.6	33.15	33.49
18-Mar-20	17:00	33.42	33.23	33.05	33.21
18-Mar-20	17:30	33.37	33.18	33.23	33.46
18-Mar-20	18:00	33.13	33.41	33.41	33.31
18-Mar-20	18:30	32.61	32.51	32.74	32.74
18-Mar-20	19:00	32.05	32.15	32.15	32.04
18-Mar-20	19:30	31.46	31.56	31.53	31.48
18-Mar-20	20:00	31.13	31.18	31.2	31.15
18-Mar-20	20:30	30.62	30.7	30.67	30.65
18-Mar-20	21:00	30.14	30.24	30.24	30.19
18-Mar-20	21:30	29.54	29.66	29.64	29.64
18-Mar-20	22:00	29.02	29.16	29.16	29.16
Average		32.09	32.09	32.06	32.04
Max.		33.7	33.68	33.73	33.65
Min.		29.02	29.16	29.09	28.97
Range		4.68	4.52	4.64	4.68

		250 cm above ground level			
		Temperature (C°)			
Date	**Time**	**Control Site**	**Treatment 1**	**Treatment 2**	**Treatment 3**
18-Mar-20	10:30	29.07	29.14	29.09	29.11
18-Mar-20	11:00	30.77	30.55	30.55	30.27
18-Mar-20	11:30	31.94	32.02	31.71	31.48
18-Mar-20	12:00	31.51	31.69	31.71	31.74
18-Mar-20	12:30	32.46	32.79	32.95	32.74
18-Mar-20	13:00	32.66	33.05	33.29	33.23
18-Mar-20	13:30	32.92	32.98	33.31	33.37
18-Mar-20	14:00	32.69	32.95	33.16	33.37
18-Mar-20	14:30	32.82	32.79	32.79	32.69
18-Mar-20	15:00	32.95	32.66	32.54	32.69
18-Mar-20	15:30	33.52	33.6	33.08	33.31
18-Mar-20	16:00	33.05	33.34	33.23	33.21
18-Mar-20	16:30	33.44	33.52	33.05	33.31
18-Mar-20	17:00	33.34	33.39	33.31	33.28
18-Mar-20	17:30	33.29	33.28	33.21	33.18
18-Mar-20	18:00	33	33.23	33.18	33.05
18-Mar-20	18:30	32.48	32.64	32.61	32.54
18-Mar-20	19:00	31.92	31.84	32.04	31.94
18-Mar-20	19:30	31.31	31.46	31.43	31.4
18-Mar-20	20:00	30.95	31.08	31.05	31.07
18-Mar-20	20:30	30.47	30.6	30.6	30.57
18-Mar-20	21:00	29.97	30.07	30.06	30.06
18-Mar-20	21:30	29.41	29.51	29.53	29.53
18-Mar-20	22:00	28.84	29.04	29.03	29.03
Average		31.87	31.97	31.94	31.92
Max.		33.52	33.6	33.31	33.37
Min.		28.84	29.04	29.03	29.03
Range		4.68	4.56	4.28	4.34

Appendix E – Surface temperature

Surface temperature data recorded at the Bowen Street during data collection on 18 March 2020. Control * describes the area of new asphalt that appears on the control surface.

Time	Control	Control *	Treatment 1	Treatment 2	Treatment 3
10:30	33.5		33.1	30.8	32
11:00	35.1	37.9	35.6	33.5	34.1
11:30	41.8	45.7	45	42.1	42.7
12:00	43.5	46.45	44.5	42.15	42.7
12:30	45.2	47.2	44	42.2	42.7
13:00	47	49.2	47.3	44.8	44.8
13:30	46.9	50.5	46.9	44.3	44.5
14:00	45.7	46.9	44	43	42.7
14:30	44	44.8	43.7	41.9	41.5
15:00	43.6	45	44.8	42.2	41.9
15:30	43.7	44.5	43	41.5	40.9
16:00	42.2	44.2	41.2	40.1	39.5
16:30	44.2	45.2	42.2	41.2	40.6
17:00	40.7	41.6	40.1	39.3	38.4
17:30	41.3	41.8	40	38.9	38.1
18:00	38.7	39.5	37.8	37	36.4
18:30	36.8	37.1	35.7	35.3	34.8
19:00	35.7	36	35.6	34.5	34.1
19:30	35	35.1	34	33.3	32.8
20:00	35.6	35.4	34.1	33.8	32.8
20:30	33.8	34	33	32.6	32.3
21:00	33.6	33.6	32.4	31.6	31.4
21:30	32.8	33.3	32	31.3	31.3
22:00	32.1	32.1	31.3	30.3	30.3
Average	39.69	41.18	39.22	37.82	37.64
Max	47	50.5	47.3	44.8	44.8
Min	32.1	32.1	31.3	30.3	30.3
Range	14.9	18.4	16	14.5	14.5