Hort Innovation

Final Report

Conveying the benefits of living turf - Mitigation of the urban heat island effect

Project leader:

Dr Mark Siebentritt

Delivery partner:

Seed Consulting Services

Project code:

TU18000

Project:

Conveying the benefits of living turf - Mitigation of the urban heat island effect TU18000

Disclaimer:

Horticulture Innovation Australia Limited (Hort Innovation) makes no representations and expressly disclaims all warranties (to the extent permitted by law) about the accuracy, completeness, or currency of information in this Final Report.

Users of this Final Report should take independent action to confirm any information in this Final Report before relying on that information in any way.

Reliance on any information provided by Hort Innovation is entirely at your own risk. Hort Innovation is not responsible for, and will not be liable for, any loss, damage, claim, expense, cost (including legal costs) or other liability arising in any way (including from Hort Innovation or any other person's negligence or otherwise) from your use or non-use of the Final Report or from reliance on information contained in the Final Report or that Hort Innovation provides to you by any other means.

Funding statement:

This project has been funded by Hort Innovation, using the Turf research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978-0-7341-4598-7

Published and distributed by: Hort Innovation

Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

Content

Content	3
$ummary	4
Keywords	5
Introduction	6
Methodology	7
Outputs	10
Outcomes	12
Monitoring and evaluation	15
Recommendations	17
Refereed scientific publications	18
References	19
Intellectual property, commercialisation and confidentiality	20
Acknowledgements	21
Appendices	22

Summary

Urban heat impacts the health and well being of people living in cities and towns and has negative consequences for the economy. Urban heat islands form in cities where heat accumulates, due in part to the loss of urban greening and replacement with hard, constructed surfaces that absorb and retain heat. As such, communities, developers and governments across Australia are seeking to better understand how to manage the urban landscape and select land surface types that encourage the development of cool rather than hot cities.

The broad objective of this project was to provide the evidence base for the turf industry to further engage in a conversation with the community and industry about the benefits of living turf for mitigating the urban heat island (UHI) effect compared with synthetic turf. This evidence base was prepared by combining existing spatial (thermal) data set, additional field data and the results of urban heat modelling.

The project found that across the study sites in New South Wales, Victoria and South Australia, the surface temperature of irrigated natural turf measured 4.9°C cooler than the baseline average surface temperature. In this analysis, synthetic turf – long pile was one of the hottest surfaces in the landscape measuring nearly 11 °C hotter than average. In some instances the surface temperature of synthetic turf was recorded at over 70°C.

There was evidence of a difference in the warming potential of synthetic turf with long versus short pile (i.e. the length of the artificial grass blades), with long pile having a greater average surface temperature. In contrast, the surface temperature of bitumen was consistently between synthetic turf – long pile and synthetic turf – short pile. On average, non-irrigated natural turf provides a more moderate (1.3°C) but highly variable cooling influence, ranging from 4.4°C cooling in Victoria, to a 1.7°C warming in South Australia. The cooling benefits of non-irrigated living turf depends heavily on the seasonal rainfall during the year of data collection.

The results suggest that in large areas of open space such as occurs around irrigated sporting and recreation fields and parks and reserves, the cooling benefits from living turf are significant enough to outweigh the warming effects of surfaces such as synthetic turf and bitumen. In these areas the localised warming that does occur appears to be quickly mixed with cooler surrounding air, especially when there is a light breeze. As such, people walking or playing sport over these surfaces benefit from what might be considered as "borrowed cooling" from nearby cooler areas. The extent of this borrowed cooling effect requires further investigation.

In residential settings, the analysis found that where surface materials lead to an increase in air temperature by 1.85°C and where residences only have cooling installed, the consistently warmer air temperatures resulting from the urban heat island effect have the potential to raise annual cooling energy use and associated utility costs by about 50% for Sydney and Adelaide and up to 72% in Melbourne.

The analysis of the thermal performance of the five landscape coverings in this project reinforces that natural materials, in this case living turf, provide a cooling influence compared with selected built materials that provided a warming influence. Future studies into the urban heat mitigation benefits of living turf should consider the impact of different surface materials such as living versus synthetic turf in courtyard settings where wind movement is limited and on street verges where high near surface temperatures could impact on the establishment of street trees.

Keywords

Living turf, artificial turf, urban heat, urban heat islands, urban heat island mitigation, surface temperature

Introduction

Background

The liveability of cities and their resilience to climate change is influenced by a range of factors including the extent and quality of green infrastructure and the presence of urban heat islands. The transition from natural landscapes and areas with large amounts of green cover to artificial or constructed landscapes in cities is leading to greater accumulation of heat and the creation of hot spots and urban heat islands.

The drivers of urban cooling and heating are becoming increasingly well understood. Green infrastructure or green cover includes a wide range of land surface types, including turf (grass), tree canopy, shrub canopy, green walls and green roofs. It is typically associated with cooler land surface areas, due to the cooling effect of evapotranspiration from the surface of plants. In contrast constructed materials such as bitumen roads, dark colored roofs, rubber soft fall and synthetic turf are associated with higher surface temperatures.

The use of synthetic turf is becomingly increasingly popular in Australia as an alternative to living turf for use in gardens and sports and recreation fields. It is promoted as a low maintenance (e.g. no mowing, watering, fertilising) and high wear and tear. Synthetic turf is typically constructed of plastic fibres that replicate the blade of a grass with a base layer of polypropylene. “Third generation” synthetic turf, which is produced for sports such as football and rugby are manufactured from longer polyethylene fibres filled with sand for stability and rubber granules for shock absorption, elasticity and suitability for sliding.

The potential impact of synthetic turf on heat accumulation has been observed through a number of recent studies, although a number of these have been part of broader investigations into heat islands and the materials that influence land surface temperature. These studies suggest that synthetic turf can have amongst the hottest land surface temperatures in an urban landscape on a hot day, and well above a city-wide average. In contrast, living turf is associated with temperatures lower than city wide averages. Given that surface temperature can impact air temperature, it is possible that increasing use of synthetic turf is reducing human thermal comfort, increasing the cost of cooling buildings, and reducing overall human health and well-being in close proximity to where it is being used.

Objectives and structure

The broad objective of this project was to provide the evidence base for the turf industry to further engage in a conversation with the community and industry about how living turf is better at mitigating the urban heat island (UHI) effect compared than synthetic turf. The specific objectives were to:

- determine the influence of living turf and synthetic turf on the UHI effect in Australian capital cities and urban areas using modelling and simulating approaches;
- determine how changes in living and synthetic turf coverage can influence the UHI effect now and in future years, drawing on climate change information and changing development patterns; and
- convey the benefits of living turf in mitigating the UHI effect.

The results of this analysis provide information, especially in relation to the surface temperature of living turf, synthetic turf and other land surface types, that can be used by the turf industry, developers and government agency staff for capacity building, awareness raising and to inform decision about land use planning and development.

Methodology

Land use thermal performance

Land surface temperature data were provided by councils in New South Wales, Victoria and South Australia in absolute temperatures. In order to compare these temperatures across data sets that were collected on different days under different conditions, the absolute temperatures were converted to relative temperatures. This was done using a proprietary methodology that converts the temperatures into the degrees above or below baseline temperatures. The relative temperatures equate to the warming or cooling influence (thermal performance) of the land surface feature, respectively.

Within each of the three states, five landscape features were targeted as potential replacements in landscape decisions (Table 1). For each feature type, approximately 100 examples were identified within each state. Using the relative temperature data, the thermal performance for each example was calculated, resulting in 1,580 individual measurements. These measurements are aggregated for each feature type nationally and at the state level to understand the broader impacts of landscape decisions and regional variation.

Table 1. Land feature types included land surface temperature assessment.

Surface type	Description	Examples
Irrigated living turf	Areas of green healthy living turf [1]with visual irrigation patterns	Golf courses, sports fields, reserves, gardens
Non-irrigated living turf	Areas of maintained vegetation with no evidence of irrigation	Reserves, sports fields surrounds, non-irrigated areas of golf courses
Synthetic turf – long pile	Large fields of synthetic turf playing surfaces	Hockey clubs, futsal fields
Synthetic turf – short pile	Thin synthetic turf coverings	Yardscapes, cricket nets
Bitumen	Dark hardscaped driving surfaces	Parking lots, roads

Surface-to-air relationship assessment

There are two types of heat important in understanding drivers of thermal comfort: surface temperature and air temperature. Surface temperature has a major influence on air temperature, but air temperature is also influenced by land surfaces surrounding a given point. Additionally, thermal comfort, or how humans experience temperature, is also affected by relative humidity, wind, and other local climatic conditions.

To incorporate these aspects into the analysis, an air temperature assessment was conducted in NSW, Victoria and South Australia to measure the influence of living turf on thermal comfort across a range of environments and climates, focusing on the boundaries where irrigated living turf encounters other landscape types: bitumen, bare ground, playing courts, non-irrigated turf, and synthetic turf – long pile.

In each State in the area where land surface temperature data was acquired (i.e. Adelaide, SA; Port Phillip and Moreland, VIC; and Parramatta, NSW), a temperature sensor array over a span of 8 meters consisting of six Kestrel Heat Stress Weather Sensors (models 4400 and 5400) was deployed over the five land surface types for a period of approximately 1 hour each (Figure 1).

These assessments were undertaken on hot days (greater than 33 °C) that were preceded by at least one warm day (greater than 30 °C) to allow the landscape to warm thoroughly. These conditions were met on February 2nd, 2019 in Adelaide, February 3rd, 2019 in Melbourne, and February 12th, 2019 in Parramatta. BOM forecast maximum temperatures for these days were 36 °C, 39 °C, and 37 °C, respectively. All measurements were taken

[1] While species type was not assessed, it is understood that the different locations consisted mostly of kikuyu.

during the hottest period of the day between 11 am and 4 pm.

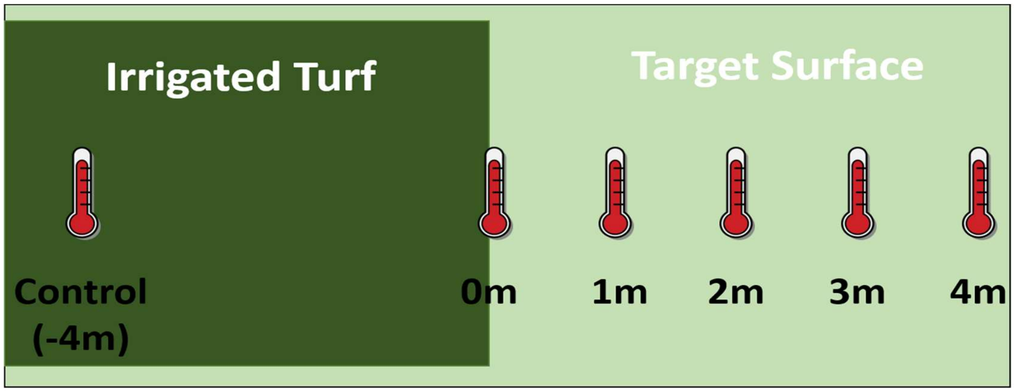


Figure 1. Illustration of transect for measuring air temperature, thermal comfort, and land surface temperature.

In addition to assessing air temperatures for each transect, thermal comfort was also assessed by calculating Universal Thermal Climate Index (UTCI) values at each station. UTCI incorporates air temperature, radiative temperature (influence of direct sunlight), relative humidity, and wind speed in calculating the apparent temperature humans feel in those conditions, given in terms of degrees Celsius**Error! Reference source not found.**. For each of the six stations on the transect, UTCI values were calculated according to the equations given in Blazejczyk et al. (2013).

Thermal comfort and energy use

Outdoor thermal comfort

In developing a methodology to simulate outdoor comfort, the team screened thermal modelling tools for their ability to both produce outdoor surface temperatures, and to calculate the cooling effects of evapo-transpiration of plants, which is critical to modelling the surface temperature of living turf. Only EnergyPlus has this capability, so it was selected to provide outdoor surface temperature simulations as well as indoor air-conditioning energy use for the analysis. Thermal comfort was calculated over two time scales. First, for a single moment (also called a moment-in-time calculation), and second, across a series of moments to investigate how changing environmental conditions change comfort over time.

To calculate UTCI, most of the inputs were taken from a weather data file captured at weather stations near the field study locations. These data files included hourly measurements of solar radiation, wind velocity and humidity. This method of calculating UTCI using the air temperature from the weather file rather than a localised air temperature simulation was supported by the measured data.

Indoor thermal comfort

If outdoor conditions change substantially, they will also affect comfort in adjacent buildings. To test the effect of increased ground temperature resulting from varying ground materials on indoor comfort, a single-story residential room with a large window was modelled and located adjacent to an outdoor area with ground that was changed between surface temperatures representing irrigated living turf and synthetic turf. This provides insights into the indoor thermal comfort impact that might be experienced in homes or buildings in schools. The room modelled had wall, floor, and roof construction that complies with thermal insulation requirements of the National Construction Code at the time of analysis.

Energy assessment

To account for the potential warming that may occur under some circumstances due to surface material selection, the impact to heating and cooling energy was simulated by assigning an average air temperature increase of 1.85°C across every hour of the year. This is intended to represent the urban heat island effect and aligns with the average projected increase in air temperatures due to climate change by mid century. The consistent temperature increase of 1.85°C is not necessarily how urban heat island temperature profiles would be distributed either spatially or across a 24-hour daily temperature cycle, but the order of magnitude is appropriate and sufficient to represent the general change in indoor conditioning energy. Results from this urban heat island affected weather file were compared to results from the original, unaltered weather file.

Extension

The focus of extension activities was on providing a summary of key results to turf industry members, developers and government agency staff. This was done through (a) developing an article for the turf industry e-news and Turf Australia magazine, (b) conference presentations, (c) a national seminar series and (d) development and distribution of a key findings fact sheet. Further details of these activities are provided in the Output section of this report.

Outputs

Reports

Supplementary technical reports have been submitted for this project as part of milestone reports 103 and 104. A summary of the methodology, outcomes and recommendations contained in these reports is provided in this Final Report. The technical report is provided at Appendix A.

Extension

Fact sheet

A fact sheet was produced that contained key findings for the project. These were printed and distributed at all of the seminars (listed below). A copy of the fact sheet is provided in Appendix B.

Turf industry publications

- Turf Industry e-news
  - 16 August 2019

    Living turf: A cool option for reducing heat in our cities - https://www.turfaustralia.com.au/communications?command=article&id=1825&contact_id=2&r=A&message_id=292&utm_source=communications&utm_medium=email&utm_campaign=Living+turf%3A+A+cool+option+for+reducing+heat+in+our+cities
  - 15 November 2019

    Living turf: A cool option for reducing heat in our cities -

    https://www.turfaustralia.com.au/newsletters/id/300
- Turf Australia magazine
  - Spring Edition

    Living turf: A cool option for reducing heat in our cities -

    https://www.turfaustralia.com.au/documents/item/558

Conference presentations

- Landscape Irrigation Conference (18 – 20 June 2019) – Presentation by Mark Siebentritt. Audience focused on members of the landscape irrigation sector.
- Heat and Habitat Symposium (9 – 10 December 2019) – Presentation by Mark Siebentritt. Audience focused on local and state government practitioners and national and international researchers.
- How Water Sensitive Cities Deliver Health Outcomes Seminar and Workshop (23 August 2019) – Presentation by Prof Nigel Tapper (including results from TU18000). Audience focused on Western Australian councils.

Radio interview

- 24 November 2019 - 6PR interview with Sue McDougall on "The Gardening Show. Discussing urban heat and the Perth seminar. Audience covers Metropolitan Perth.

National seminar series (all presented by Mark Siebentritt)

The following list of presentations is ordered chronologically.

- Victoria
  - Melbourne (23 August 2019). Seminar summarising key findings and recommendations hosted by the City of Monash. Open invite across local and state government and the turf industry. Attendees = 12.
- South Australia
  - Adelaide (28 August 2019). Seminar summarising key findings and recommendations hosted by the City of Charles Sturt. Open invite across local and state government and the turf industry. Attendees = 17.
- Queensland
  - Brisbane (17 October 2019). Presentation summarising key findings and recommendations to the Turf Queensland AGM. Attendees = 7.
  - Brisbane (17 October 2019). Presentation summarising key findings and recommendations to Brisbane City Council. Attendees = 9.
- New South Wales
  - Sydney (23 October 2019). Presentation summarising key findings and recommendations hosted by Burwood Council. Open invite to Southern Sydney Regional Organisation of Councils (SSROC) councils. Attendees = 9.
- Western Australia
  - Perth (28 November 2019). Presentation summarising key findings and recommendations provided as part of the University of Western Australia's Environmental Science Seminar Series. Open invite across state and local government and the turf industry. Attendees = 10.

A copy of the standard presentation slides is provided at Appendix C.

Outcomes

The intermediate outcomes identified for this project as per the M&E Plan were to:

1. Improve understanding of the ability of living grass to mitigate the UHI effect
2. Increase awareness of the benefits of living turf in mitigating the UHI effect
3. Encourage adoption of living turf as a proactive landscaping/planning strategy to mitigate the UHI effect

The end of project outcome was "Providing \the evidence base for the turf industry to further engage in a conversation with the community and industry about how living turf is better at mitigating the urban heat island effect compared to synthetic turf".

The way in which intermediate outcomes 1 and 2 listed above have been met during the project are described below. Intermediate outcome 3, which involves adoption of living turf in landscaping/planning, is a result of Intermediate outcomes 1 and 2 and its assessment is beyond the scope of this project.

Improve understanding of the ability of living grass to mitigate the UHI effect

Land use thermal performance assessment

Based on analysis of landscape scale thermal data sets in three states (NSW, SA and VIC), the following key findings have been identified:

- Across the country, the surface temperature of irrigated natural turf measures 4.9 °C cooler than the baseline average surface temperature.
- In this analysis, synthetic turf – long pile was one of the hottest surfaces in the landscape measuring nearly 11°C hotter than average.
- There is evidence of a difference in the warming potential of synthetic turf with long versus short pile (i.e. the artificial grass blades), with the former having a greater average surface temperature. In contrast, bitumen which was included as a control, consistently fell between synthetic turf – long pile and synthetic turf – short pile.
- On average, non-irrigated natural turf provides a more moderate (1.3 °C) but highly variable cooling influence, ranging from 4.4 °C cooling in Victoria, to a 1.7 °C warming in SA. The thermal performance of non-irrigated living turf depends heavily on the seasonal precipitation during the year of data collection.
- The analysis of the thermal performance of the five landscape coverings reinforces that natural materials provide a cooling influence compared with built materials that provide a warming influence.

Surface-to-air relationship assessment

Field data was collected along transects across six surface types (irrigated living turf, non-irrigated living turf, synthetic turf, bitumen, playing courts and bare ground) during the 2018-19 summer period for air and surface temperature in NSW, SA and VIC. The following key findings have been identified:

- When compared with irrigated living turf, natural materials (bare ground and non-irrigated living turf) averaged 10 °C warming over the target surface (between the 1 m and 4 m marks), whereas synthetic materials (playing court, bitumen, and synthetic turf) averaged 23°C of warming.
- At all times during the three hot days of data collection, average surface temperatures over irrigated living turf remained between 34 and 42 °C. Temperatures over the target surfaces ranged from 42 to 70°C, with synthetic turf being the hottest measuring between 25 and 33 °C hotter than irrigated living turf between the 1 and 4 m marks. Peak temperatures over 70°C for synthetic turf align with observations of the same material recorded in studies by Jim (2017).
- The analysis of air temperature data shows a strong negative correlation between maximum air temperatures and wind speed. This means that increased wind speeds diminish the maximum air temperatures recorded over a given surface type, in many cases masking the impact of the much higher surface temperatures of constructed or synthetic materials.
- The impact of wind mixing on air temperature at 1.2 m above the surface was shown by collection of data closer to the ground, where mixing is less pronounced. For example, the near-ground air temperature sensors

deployed at 10 cm height over the synthetic turf in Victoria and NSW showed a much stronger relationship between surface and air temperature, with 10 cm high sensors measuring 5.9 and 4.5 °C warmer, respectively, than the 1.2 m high sensors, even in moderate wind conditions.

- A key metric explored in the study was the Range of Influence (RoI) which is the limit at which the cooling influence of irrigated living turf is no longer measurable. Land surface temperature data collected along each transect provided the strongest example of how temperatures vary with distance from irrigated natural living turf. UTCI provided the second strongest signal of the cooling influence of irrigated living turf.
- All of these data are within several degrees of the BOM average at the time of collection, suggesting air temperatures are the product of a much larger area, much of which may lay beyond the range of the 8 m transect. Additional investigations in to the scale of variation is needed. Furthermore, wind speeds of over 1m/s seem to be a critical threshold for the transference of surface temperatures into air temperatures with calmer winds allowing those patterns to be revealed, while stronger winds mix the air sufficiently to obscure any pattern.

While the aim of this study was not to understand the underlying mechanisms behind the additional heat stored in synthetic turf, this has been explored to aid understanding of the results. There appears to be no specific peer reviewed literature on this issue, however, based on an understanding of structure of synthetic turf, it is likely that the increased temperature is due to a combination of materials including the pile or plastic filaments used as the grass leaves, the rubber crumb which is used in some synthetic turf to provide flexibility and ease the impact when the surface is being used for sport, and the synthetic mat.

Simulated thermal comfort and energy use

Simulated thermal comfort was assessed because of its potential ability to model the different impacts of living versus synthetic turf on air temperature and hence thermal comfort outdoors and indoors. Key findings of the simulated thermal comfort analysis were that:

- Based on scenarios assessed for Sydney, Melbourne and Adelaide, outdoor thermal stress is increased a little (1°C) by the increased surface temperature of synthetic turf, and up to 8°C in cases where a warm surface is sheltered from any prevailing breezes. The results illustrate that for the scenarios analysed, synthetic turf has consistently higher heat stress predicted than irrigated turf.
- The analysis sought to identify the number of hours when ambient air temperature was > 28°C and unobstructed wind speed was < 2 m/s. The results showed that there are a limited number of hours with coincident still air and warm temperatures, which suggests that localised shelter from prevailing breezes will be the predominant factor in determining whether a location experiences air warmed by increased ground temperature.

Outdoor thermal comfort modelling of energy use used an estimated impact of urban heat island warming of 1.85°C. This temperature was selected to also align with projected mid-century impacts of climate change. The results of the analysis were that:

- In areas that experience urban heat islands and where residences only have cooling installed, the consistently warmer air temperatures resulting from the urban heat island effect have the potential to raise annual cooling energy use and associated utility costs by about 50% for Sydney and Adelaide and up to 72% in Melbourne.
- While the 1.85°C urban heat island effect increases summer air conditioning loads, it can also provide a beneficial reduction in winter space heating needs. The net energy use across both seasons is ultimately influenced by the type and efficiency of heating and cooling systems.

Climate change and heat island mitigation

Urban heat islands are not a consequence of climate change. They exist independently of climate change, however, the way in which people experience periods of extreme heat will be worse in heat islands. A consequence of warmer and drier conditions due to climate change, which are predicted for major capital cities in Australia, is that (a) larger areas of open space will become dried grass, contributing even more to the development of urban heat islands, and/or (b) the need for increased irrigation to maintain healthy living turf. This highlights the need for local government, developers and residents to continue to proactively work together to ensure that suitable water sources, some of which may be alternative (e.g. recycled stormwater), continue to be available in the future.

Increase awareness of the benefits of living turf in mitigating the UHI effect

The project undertook a series of extension activities designed to increase awareness of the benefits of living turf in mitigating the urban heat island effect. A description of the extension activities and products is presented in the Outputs section of this report.

Monitoring and evaluation

The M&E Plan for this project identified a series of Key Evaluation Questions (KEQs). Responses to these questions are described below.

To what extent has the project achieved its expected outcomes?

The project intermediate outcomes as well as the extent to which they have been achieved are describe below:

1. Improve understanding of the ability of living grass to mitigate the UHI effect - New information has been generated from analysis of existing data, additional field data collection and modeling that improves understanding of the ability of living grass to mitigate the UHI effect. This is described in the Outcomes section of this report.
2. Increase awareness of the benefits of living turf in mitigating the key findings I effect – Awareness was increased via the extension activities undertaken, including turf industry publications, seminar series, conference presentation and the fact sheet.
3. Encourage adoption of living turf as a proactive landscaping/planning strategy to mitigate the UHI effect – Assessing increased adoption of living turf in landscaping/planning is beyond the scope of this project.

The end of project outcome was "Providing \the evidence base for the turf industry to further engage in a conversation with the community and industry about how living turf is better at mitigating the urban heat island effect compared to synthetic turf". The results of this project have provided a clear evidence base to further engage in a conversation with the community and industry about how living turf is better at mitigating the urban heat island effect compared to synthetic turf, especially through the provision of key statistics on surface temperature.

How relevant was the project to the needs of intended beneficiaries?

The content of communications material (fact sheet, conference presentations, seminar series, e-news) was designed specifically to meet the needs of the intended target audience.

The primary opportunity to ask the target audience whether the key findings were relevant to their needs was following the seminar series presentations. Attendees at the seminar series were provided with feedback forms and asked two questions, each with a five point scale:

- *Please indicate how relevant you thought the content was for your organisation (Very relevant, relevant, no opinion, not relevant, not very relevant)*

  90% of feedback form respondents indicated that they thought the content was "very relevant" (the highest positive response) and the remaining 10 said that it was "relevant" (the second highest response)

- *Please indicate how engaging you found the presentation style and approach (Very engaging, engaging, no opinion, not engaging, not very engaging)*

  86% of feedback form respondents indicated that they thought the content was "very engaging" and the remaining 14% said that it was "engaging".

Additional comments included:

- Very well presented and engaging with the audience
- "Provide sources of research and business cases"
- "Need to spread the message to decision makers"
- "So much to share with engineers and parks and designers at council"
- "More information on cost savings and cool roads"

How well have intended beneficiaries been engaged in the project?

The primary intended beneficiaries were turf industry members (growers through to retailers) and planning and development industry professionals in the local and state government sectors around Australia.

Turf industry members have been engaged by:

- Development of communications material (Turf Australia magazine article, e-news) distributed to Turf Australia members;
- Attendance at the national seminar series events with the assistance of invitations from Turf Australia and state based turf industry organisations;
- Attendance at the Landscape Irrigation Conference

Local and state government representatives have been engaged by:

- Attendance at the national seminar series events with invites being distributed by individual councils and local and state government networks;
- Attendance at the Heat and Habitat Symposium and the How Water Sensitive Cities Deliver Health Outcomes Seminar and Workshop.

Overall, attendance rates at the seminar series was slightly lower than anticipated, however, numerous requests were received by attendees asking that the slide deck be provided so that it can be distributed within their networks. This suggests that the reach of the material presented at the workshops was greater than those who attended.

All beneficiaries have also been engaged through the distribution of key findings fact sheets.

<u>To what extent were engagement processes appropriate to the target audience/s of the project?</u>

Turf Australia publications were effective for the target audience because they were distributed to industry members through established communications channels. Click rate

The face to face presentations were suitable for local and state government staff who wanted to request further information by attending the seminars. Overall, attendance rates at the seminar series was slightly lower than anticipated, however, numerous requests were received by attendees asking that the slide deck be provided so that it can be distributed within their networks. This suggests that the reach of the material presented at the workshops was greater than those who attended.

Recommendations

The results suggest that in large areas of open space such as in occurs around irrigated sporting and recreation fields and parks and reserves, the cooling benefits from living turf are significant enough to outweigh the warming effects of surfaces such as synthetic turf and bitumen. In these areas the localised warming that does occur appears to be quickly mixed with cooler surrounding air, especially when there is even a light breeze. As such, the people walking or playing sport over these surfaces benefit from what might be considered as "borrowed cooling" from nearby cooler areas. It is anticipated that as the proportion of hot surfaces to cool surfaces increases, the overall warming signal will become stronger.

While not extensively tested for this study, the results suggest that in closed in settings, such as fenced in backyards or private open space surrounded by buildings, the reduced air mixing due to lower breezes could mean that hot surfaces can more directly lead to warmer air temperatures. For example, this means that for a small home with a fenced in courtyard, living turf could be seen to more directly reduce air temperatures and improve thermal comfort, whereas synthetic turf could more directly lead to increased temperatures and reduced thermal comfort. The liveability of such spaces will also be more directly influenced by surface temperature. For example, in a backyard with limited space the extreme temperatures of synthetic turf could prove dangerous for walking with no shoes or for the unprotected feet of pets such as dogs.

A further consideration is the use of living versus synthetic turf in streetscapes, especially road verges. The higher surface temperature of synthetic turf placed over the soil surface in verges potential a significant potential risk to street tree survival and longevity due to the higher surface temperature translating to higher root temperatures. Further, the otter soil surface can reduce moisture content and more rapidly dry out the root zone. Other impacts could be less desirable verge side areas for pedestrians.

This study provides clear, consistent information about the relative benefit of living turf in reducing surface temperatures compared with other surface materials such as synthetic turf. The evidence base in this regard is arguably amongst the most comprehensive of any in Australia. The implications of surface temperature for nearby air temperature and thermal comfort reflect the importance of local context such as exposure to wind.

Future research on the heat mitigation benefits of living turf should assess the following:

- The impact of higher relative surface temperatures of synthetic turf compared with living turf on the longevity and survival of street trees, given the importance of street trees for urban cooling and the costs associated with their establishment and maintenance;
- The influence of species type on temperatures as a result of factors such as texture and inherent rates of evapotranspiration;
- The impact of living versus synthetic turf in closed in areas, such as backyards, such as occur in courtyard homes, on liveability for people and pets;
- Irrigation requirements to generate cooling benefits from living turf. This should also consider the role of soil health in creating healthy, living turf;
- The underlying mechanisms influencing the additional heat stored in synthetic turf;
- The impact of increased ground temperature on indoor temperatures in apartments, including upper level apartment rooms; and
- Options for including estimates of the impact of living turf versus other land surface types on surface temperature in urban heat island analysis tools such as those developed by the CRC for Water Sensitive Cities.

Refereed scientific publications

There were no refereed scientific publications published during the reporting period that can be attributed or partly-attributed to the project.

References

Blazejczyk, K., Jendritzky, G., Bröde, P., Fiala, D., Havenith, G., Epstein, Y., Psikuta, A. and Kampmann, B., 2013. An introduction to the universal thermal climate index (UTCI). Geographia Polonica, Volume 86, Issue 1, pp. 5-10. http://dx.doi.org./10.7163/GPol.2013.1

Jim, C. Y., 2017. Intense summer heat fluxes in artificial turf harm people and environment. *Landscape and Urban Planning,* Volume 157, pp. 561-576.

Intellectual property, commercialisation and confidentiality

This study used surface temperature data provided by the organisations listed below. This data has been used for this project under data licence agreements (or equivalent) and each Council retains copyright of the original data.

- New South Wales: City of Parramatta
- Victoria: City of Port Phillip
- South Australia:
  - Resilient East region councils (City of Adelaide, City of Burnside, City of Campbelltown, City of Norwood Payneham St Peters, City of Prospect, City of Tea Tree Gully, City of Unley, and Town of Walkerville) and the City of Salisbury;
  - AdaptWest region councils (City of Port Adelaide Enfield, City of Charles Sturt, City of West Torrens).

All other data generated during this project is the property of Hort innovation.

There are no commercialisation issues to report.

Acknowledgements

The project team consisted of Seed Consulting Services (now Edge Environment), EnDev Geographic and Atelier Ten. The project team recognises the funding support of Hort Innovation for this project and the assistance provided by Turf Australia in providing feedback on project deliverables and for assisting with connecting with its network of members for extension activities. The Project Team recognises and thanks the following organisations for the assistance they provided during the project:

Provision of surface temperature data.

- New South Wales: City of Parramatta
- Victoria: City of Port Phillip
- South Australia:
    - City of Salisbury
    - AdaptWest region councils (City of Port Adelaide Enfield, City of Charles Sturt, City of West Torrens)
    - Resilient East region councils (City of Adelaide, City of Burnside, City of Campbelltown, City of Norwood Payneham St Peters, City of Prospect, City of Tea Tree Gully, City of Unley, and Town of Walkerville)

Field sites:

- New South Wales: City of Parramatta
- Victoria: City of Port Phillip, Moreland City Council
- South Australia: Adelaide High School

Support in the organisation of the national seminar series

- Adelaide – City of Charles Sturt, AdaptWest region of councils
- Melbourne – City of Monash
- Perth – University of Western Australia, Turf Western Australia, Cooperative Research Centre for Water Sensitive Cities
- Queensland – Brisbane City Council, Turf Queensland
- Sydney – South Sydney Region of Councils

Appendices

The following Appendices are attached to this report:

Appendix A – Technical Report

Appendix B - Fact sheet

Appendix C - Example of PowerPoint slide deck used for national seminar series

Appendix A - Technical Report

Conveying the benefits of living turf - Mitigation of the urban heat island effect

Technical Report

Prepared for Horticulture Innovation Australia

20 March 2020

seed consulting services

Conveying the benefits of living turf - Mitigation of the urban heat island effect

Technical Report

Prepared for Horticulture Innovation Australia

Prepared by:
Seed Consulting Services
106 Gilles Street, Adelaide, South Australia 5000
P. +61 8 8232 4823
W. www.seedcs.com.au

In collaboration with:

EnDev Geographic

Atelier Ten

Document Control

Document information

Information	
Document Owner	Horticulture Innovation Australia
Project ID	879 HIA TURF
Last Saved Date	2 March 2020
File Name	Technical Report - Conveying the benefits of living turf

Document history

Version	Issue date	Authors
Version 1	16 March 2019	Mark Siebentritt, Justin VanderBerg, Anna Brannon, Paul Stoller
Version 2	24 April 2019	Mark Siebentritt, Justin VanderBerg, Anna Brannon, Paul Stoller
Version 3	23 June 2016	Mark Siebentritt, Justin VanderBerg, Anna Brannon, Paul Stoller
Version 4	20 December 2019	Mark Siebentritt, Justin VanderBerg, Anna Brannon, Paul Stoller
Version 5	20 March 2020	Mark Siebentritt, Justin VanderBerg, Anna Brannon, Paul Stoller

Acknowledgements

The project team consisted of Seed Consulting Services (now Edge Environment), EnDev Geographic and Atelier Ten. The project team recognises the funding support of Hort Innovation for this project and the assistance provided by Turf Australia in providing feedback on project deliverables and for assisting with connecting with its network of members for extension activities. The Project Team recognises and thanks the following organisations for the assistance they provided during the project:

- Provision of surface temperature data: New South Wales: City of Parramatta; Victoria: City of Port Phillip; South Australia: AdaptWest region councils (City of Port Adelaide Enfield, City of Charles Sturt, City of West Torrens), City of Salisbury and the Resilient East region councils (City of Adelaide, City of Burnside, City of Campbelltown, City of Norwood Payneham St Peters, City of Prospect, City of Tea Tree Gully, City of Unley, and Town of Walkerville).
- Field sites: New South Wales: City of Parramatta; Victoria: City of Port Phillip, Moreland City Council; South Australia: Adelaide High School
- Support in the organisation of the national seminar series: Adelaide – City of Charles Sturt, AdaptWest region of councils; Brisbane – Brisbane City Council, Turf Queensland; Melbourne – City of Monash; Perth – University of Western Australia, Turf Western Australia, Cooperative Research Centre for Water Sensitive Cities; Sydney – South Sydney Region of Councils.

seed
consulting services

Contents

1 Introduction ... 1
1.1 Background ... 1
1.2 Objectives and structure ... 2

2 Land use thermal performance assessment ... 3
2.1 Context ... 3
2.2 Methods ... 5
2.3 Results ... 5
2.4 Modelling the impact of land surface change ... 10
2.5 Limitations ... 12

3 Surface-to-air relationship assessment ... 14
3.1 Context ... 14
3.2 Methods ... 15
3.3 State results ... 17
3.3.1 New South Wales ... 17
3.3.2 South Australia ... 21
3.3.3 Victoria ... 25
3.4 National results ... 30
3.4.1 Range of influence ... 34
3.4.2 Connection between surface and air temperature ... 35
3.4.3 Limitations ... 37

4 Thermal comfort and energy use ... 38
4.1 Introduction ... 38
4.1.1 Comfort factors and calculation limitations ... 38
4.1.2 Outdoor thermal comfort ... 39
4.1.3 Indoor thermal comfort ... 40
4.2 Outdoor thermal comfort ... 40
4.2.1 Method ... 40
4.2.2 Results ... 43
4.3 Indoor thermal comfort ... 50
4.3.1 Method ... 50
4.3.2 Results ... 51
4.4 Energy assessment ... 51
4.4.1 Method ... 51
4.4.2 Results ... 53

5 Consequences of climate change ... 56
5.1 Land surface changes ... 56
5.2 Thermal performance changes ... 57
5.3 Climate change in Australia ... 57
5.4 Implications for thermal comfort and energy use ... 60
5.5 Implications for adaptation ... 60

6 Key findings ... 62

References ... 67

Appendix A. Land surface temperature datasets ... 69

seed
consulting services

Table of figures

Figure 1. Land surface temperature data and surface feature locations across a) Victoria, b) New South Wales, and c) South Australia. 4
Figure 2. The thermal performance of landscape surfaces based on combined observations in Adelaide, Melbourne and Sydney. 7
Figure 3. The thermal performance of landscape surfaces in the City of Parramatta, NSW 8
Figure 4. The thermal performance of landscape surfaces in Western and Eastern Adelaide, SA. 8
Figure 5. The thermal performance of landscape surfaces in the Cities of Melbourne and Port Phillip, VIC. 9
Figure 6. CRC Extreme Heat Assessment Tool highlighting the Smith Partners Stadium and surrounds. Yellow indicates sports field replaced with synthetic grass in 2017. 11
Figure 7. Landcover fractions identified under the baseline and synthetic grass scenarios. 12
Figure 8. Overall land surface temperatures under baseline and synthetic grass scenario. 12
Figure 9. Illustration of transect for measuring air temperature, thermal comfort, and land surface temperature. 14
Figure 10. Playing court example from Parramatta, NSW (12 Feb 2019). 15
Figure 11. Synthetic turf example from Port Phillip, VIC (03 Feb 2019). 15
Figure 12. Non-irrigated natural turf example from Port Phillip, VIC (03 Feb 2019). 16
Figure 13. Bare ground example from Adelaide, SA (02 Feb 2019). 16
Figure 14. Conceptual equation of the Universal Thermal Climate Index (UTCI). 17
Figure 15. Results of NSW non-irrigated living turf thermal assessment. 17
Figure 16. Results of NSW playing court thermal assessment. 18
Figure 17. Results of NSW bitumen thermal assessment. 18
Figure 18. Results of NSW synthetic turf thermal assessment. 19
Figure 19. Results of NSW bare ground thermal assessment. 19
Figure 20. Surface temperature results of NSW thermal assessment. 20
Figure 21. Air temperature results of NSW thermal assessment. 20
Figure 22. Universal Thermal Comfort Index (UTCI) results of NSW thermal assessment. 21
Figure 23. Results of SA non-irrigated living turf thermal assessment. 21
Figure 24. Results of SA playing court thermal assessment. 22
Figure 25 Results of SA bitumen thermal assessment. 22
Figure 26. Results of SA synthetic turf thermal assessment. 23
Figure 27. Results of SA bare ground thermal assessment. 23
Figure 28. Surface temperature results of SA thermal assessment. 24
Figure 29. Air temperature results of SA thermal assessment. 25
Figure 30. Universal Thermal Climate Index (UTCI) results of SA thermal assessment. 25
Figure 31. Results of VIC non-irrigated living turf thermal assessment. 26
Figure 32. Results of VIC playing court thermal assessment. 27
Figure 33. Results of VIC bitumen thermal assessment. 27
Figure 34. Results of VIC synthetic turf thermal assessment. 28
Figure 35. Results of VIC bare ground thermal assessment. 28
Figure 36. Surface temperature results of VIC thermal assessment. 29
Figure 37. Air temperature results of VIC thermal assessment. 29

Figure 38. Universal Thermal Climate Index (UTCI) results of VIC thermal assessment. 30
Figure 39. Results of national non-irrigated living turf thermal assessment. 30
Figure 40. Results of national playing court thermal assessment. 31
Figure 41. Results of national synthetic turf thermal assessment. 31
Figure 42. Results of national bitumen thermal assessment... 32
Figure 43. Results of national bare ground thermal assessment. 32
Figure 44. Surface temperature results of national thermal assessment. 33
Figure 45. Air temperature results of national thermal assessment. 33
Figure 46. Universal Thermal Climate Index (UTCI) results of national thermal assessment. 34
Figure 47. Range of influence of irrigated living turf over varying surface types. 35
Figure 48. Ground level air temperature warming compared to 1.2m level over varying surfaces. 37
Figure 49. UTCI "feels like" temperatures and associated thermal stress categories. 39
Figure 50. PMV ratings and associated comfort categories... 40
Figure 51. Outdoor comfort relative to changing exposure. 44
Figure 52. Sydney Annual UTCI, grouped by thermal stress. 47
Figure 53. Adelaide Annual UTCI, grouped by thermal stress. 48
Figure 54. Melbourne Annual UTCI, grouped by thermal stress. 49
Figure 55. Observed and projected temperature changes in Australian cities. 58
Figure 56. Observed and projected precipitation changes in Australian cities. 59
Figure 57. Temperature change between 1990 and 2050 under RCP 8.5 according to the ACCESS model. 60

Table of tables

Table 1. Land feature types included land surface temperature assessment. 3
Table 2. Land feature types included thermal comfort assessment. 16
Table 3. Inert ground surface properties for simulation... 43
Table 4. Living turf ground surface properties for simulation. 43
Table 5. Annual cooling-only energy increase resulting from urban heat islands................. 53
Table 6. Annual cooling-only energy cost increase resulting from urban heat islands. 53
Table 7. Annual total energy increase, with gas heating, from urban heat islands.............. 54
Table 8. Annual total energy increase, with reverse-cycle electric heating, from urban heat islands. 54
Table 9. Annual total energy cost increase, with gas heating, from urban heat islands. 55
Table 10. Annual total energy cost increase, with reverse-cycle electric heating, from urban heat islands.. 55
Table 11. Individual climate change challenges for key Australian cities. 59

1 Introduction

1.1 Background

The liveability of cities and their resilience to climate change is influenced by a range of factors including the extent and quality of green infrastructure and the presence of urban heat islands. The transition from natural landscapes and areas with large amounts of green cover to artificial or constructed landscapes in cities is leading to greater accumulation of heat and the creation of hot spots and urban heat islands.

The drivers of urban cooling and heating are becoming increasingly well understood. Green infrastructure or green cover includes a wide range of land surface types, including turf (grass), tree canopy, shrub canopy, green walls and green roofs. It is typically associated with cooler land surface areas, due to the cooling effect of evapotranspiration from the surface of plants. In contrast constructed materials such as bitumen roads, dark coloured roofs, rubber soft fall and synthetic turf are associated with higher surface temperatures.

The use of synthetic turf is becomingly increasingly popular in Australia as an alternative to living turf for use in gardens and sports and recreation fields. It is promoted as a low maintenance (e.g. no mowing, watering, fertilising) and high wear and tear. Synthetic turf is typically constructed of plastic fibres that replicate the blade of a grass with a base layer of polypropylene. “Third generation” synthetic turf, which is produced for sports such as football and rugby are manufactured from longer polyethylene fibres filled with sand for stability and rubber granules for shock absorption, elasticity and suitability for sliding.

The potential impact of synthetic turf on heat accumulation has been observed through a number of recent studies, although a number of these have been part of broader investigations into heat islands and the materials that influence land surface temperature. These studies suggest that synthetic turf can have amongst the hottest land surface temperatures in an urban landscape on a hot day, and well above a city-wide average. In contrast, living turf is associated with temperatures lower than city wide averages. Given that surface temperature can impact air temperature, it is possible that increasing use of synthetic turf is reducing human thermal comfort, increasing the cost of cooling buildings, and reducing overall human health and well-being in close proximity to where it is being used.

1.2 Objectives and structure

The broad objective of this project is to provide the evidence base for the turf industry to further engage in a conversation with the community and industry about how living turf is better at mitigating the urban heat island (UHI) effect compared than synthetic turf. The specific objectives are to:

- determine the influence of living turf and synthetic turf on the UHI in Australian capital cities and urban areas using modelling and simulating approaches;
- determine how changes in living and synthetic turf coverage can influence the UHI Effect now and in future years, drawing on climate change information and changing development patterns; and
- convey the benefits of living turf in mitigating the UHI Effect.

By meeting these objectives, the results of this project can contribute to addressing the opportunities and threats as identified in the Turf Strategic Investment Plan (SIP) 2017-2021 (TSIP). Specifically, this will be done by providing baseline information on heat accumulation impacts in urban areas of living compared with synthetic turf to assist with education on the economic, environmental, social, health and wellbeing benefits of turf. Our approach will also address Outcome 1, Strategy 4 and 5 under the TSIP.

The project has a broad range of deliverables. This technical report focuses specifically on presenting the methods and results of the following tasks:

- Land-use thermal performance assessment (Section 2);
- Turf surface-to-air relationship assessment (Section 3); and
- Outdoor and indoor thermal comfort assessment (Section 4).

For consistency, this study uses the term “synthetic turf”, however, there are a broad range of commercial names given to this surface covering including artificial, waterless, fake, astro putting turf, grass and or lawn. Distinction is also made between synthetic turf long pile (>20 mm) and short pile (~10-20mm), where pile is the term for the upright blades on artificial turf.

2 Land use thermal performance assessment

2.1 Context

Land surface temperature data provide a comprehensive measure of the different thermal signatures of features across a landscape. Numerous councils across Australia have conducted high-resolution airborne land surface temperature data collection over the past five years providing unparalleled insight into how landscapes are reacting to and contributing to urban heat islands. Seed worked with 16 councils (Appendix A. Land surface temperature) across New South Wales (NSW), South Australia (SA) and Victoria (VIC) that provided access to these high resolution datasets for analysing the surface temperatures of key landscape features providing a broad, nationally representative sample of thermal performance.

These datasets have been analysed using a novel spatial processing technique to reveal the relative temperature difference (degrees Celsius warming or cooling) of each landscape feature. Within each state, five landcover types were investigated: living natural turf (irrigated), living natural turf (non-irrigated), synthetic turf – long pile (sports fields), synthetic turf – short pile (yard scape), and bitumen (as a control) (Table 1). For each landcover type, an average of 316 examples have been identified across the three states investigated, with a total of over 1,580 sites. For each site, the relative warming or cooling has been calculated providing a robust measure of the land surface temperature impact of that feature type for that climate. The difference in thermal performance of the different landscape types help refine the impact of individual landscape features and their contribution to local surface cooling.

Table 1. Land feature types included land surface temperature assessment.

Surface type	Description	Examples
Irrigated living turf	Areas of green healthy living turf with visual irrigation patterns	Golf courses, sports fields, reserves, gardens
Non-irrigated living turf	Areas of maintained vegetation with no evidence of irrigation	Reserves, sports fields surrounds, non-irrigated areas of golf courses
Synthetic turf – long pile	Large fields of synthetic turf playing surfaces	Hockey clubs, futsal fields
Synthetic turf – short pile	Thin synthetic turf coverings	Yardscapes, cricket nets
Bitumen	Dark hardscaped driving surfaces	Parking lots, roads

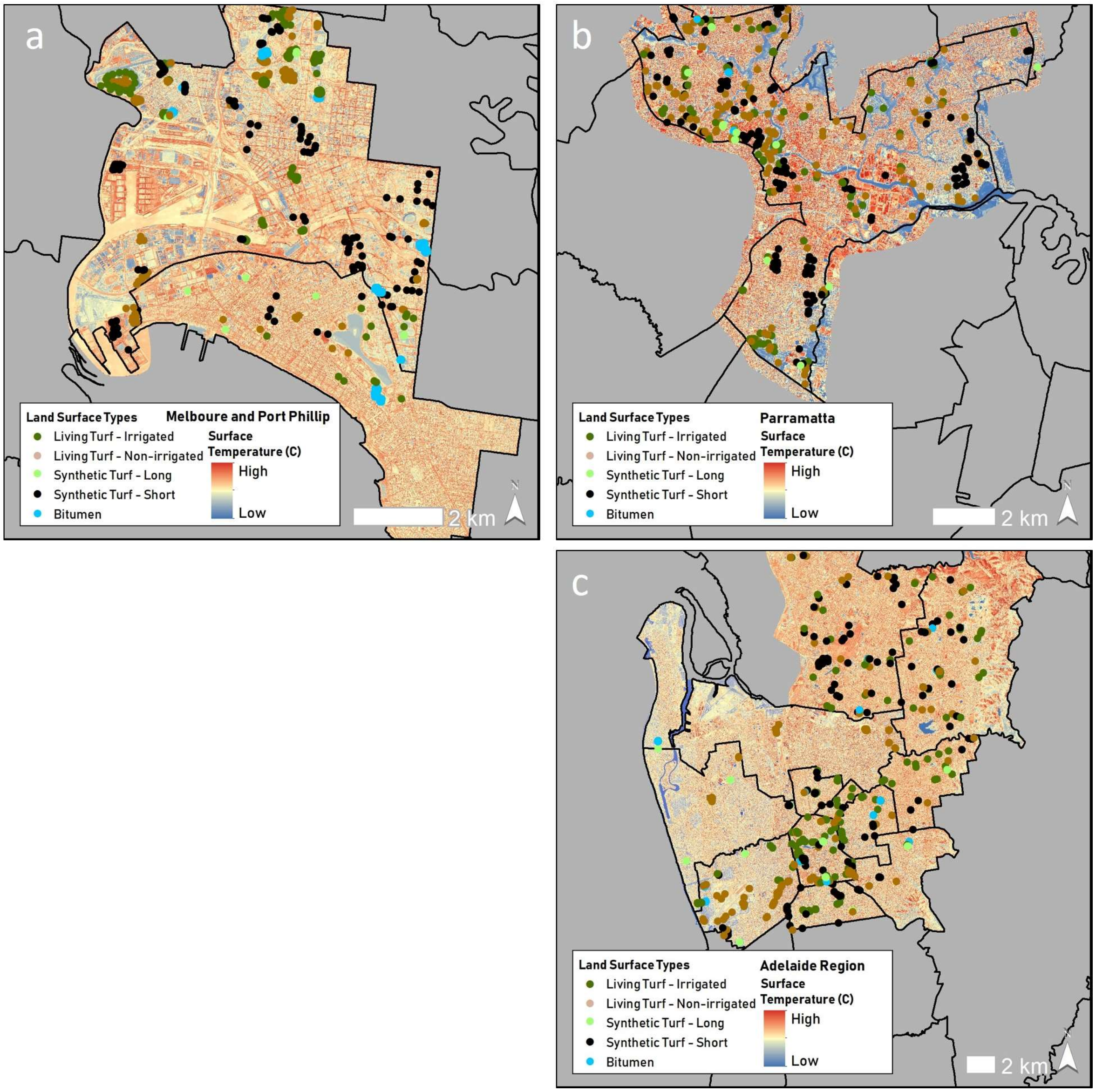


Figure 1. Land surface temperature data and surface feature locations across a) Victoria, b) New South Wales, and c) South Australia.

2.2 Methods

Land surface temperature data are provided by the councils in absolute temperatures. In order to compare these temperatures across data sets that were collected on different days under different conditions, the absolute temperatures are converted to relative temperatures. This is done using a proprietary methodology that converts the temperatures into the degrees above or below baseline temperatures. The relative temperatures equate to the warming or cooling influence (thermal performance) of the land surface feature, respectively.

Within each of the three states, five landscape features were targeted as potential replacements in landscape decisions. For each feature type, approximately 100 examples were identified within each state. Using the relative temperature data, the thermal performance for each example was calculated, resulting in 1,580 individual measurements. These measurements are aggregated for each feature type nationally and at the state level to understand the broader impacts of landscape decisions and regional variation.

2.3 Results

Across the country, the surface temperature of irrigated natural turf measures 4.9 °C cooler than the baseline average surface temperature (
Figure 2). The influence of irrigated natural turf ranged from 3.8 °C cooling in NSW (Figure 3) to 5.7 °C cooling in Victoria (
Figure 5). In addition to the increased soil moisture from irrigation, the three dimensional structure of living turf provides a broader surface area for evapotranspiration which helps drive the cooling effect of irrigated living turf.

On average, non-irrigated natural turf provides a more moderate (1.3 °C) but highly variable cooling influence, ranging from 4.4 °C cooling in Victoria, to a 1.7 °C warming in SA (

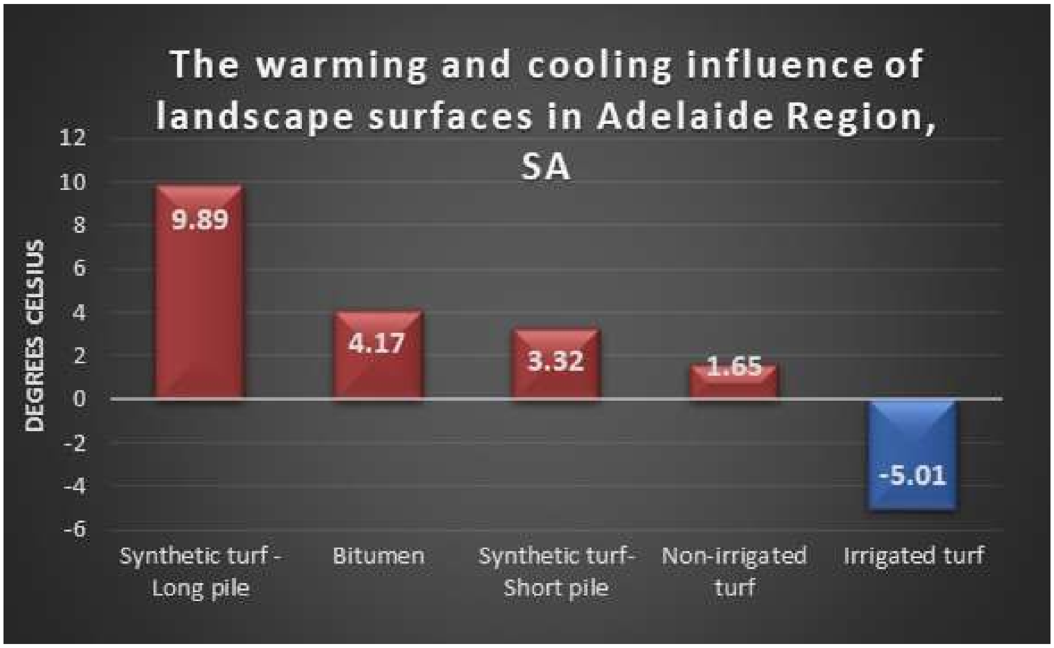


Figure 4). The thermal performance of non-irrigated living turf depends heavily on the seasonal precipitation during the year of data collection. During wetter years, non-irrigated living turf preforms similarly to irrigated living turf (as illustrated by the Victorian data), while during drier years it preforms more similarly to bitumen and other hard, dry surfaces (as illustrated by the South Australian data).

In this analysis, synthetic turf – long pile was one of the hottest surfaces in the landscape measuring nearly 11 °C hotter than average (Figure 1). This pattern has been documented in previous studies (Seed Consulting Services, Airborne Research Australia and EnDev Geographic, 2017; Seed Consulting Services, EnDev Geographic and Monash University, 2018) and is further supported by field measurements taken during the thermal comfort assessment (Section 3) where spot measures recorded surface temperatures over 70 °C.

Furthermore, synthetic turf – long pile is one of the most consistently hot surfaces only varying from 9.9 °C to 12.5 °C above average in SA and VIC, respectively. Whereas the three dimensional surface of living turf provides additional surface area for cooling, the three dimensional structure of synthetic turf provides additional surface area for heating, which is most likely stored in the rubber content of the turf (See Section 4 for further discussion).

Synthetic turf – short pile, provided a similarly consistent but more moderate warming influence, measuring 3 °C warmer than average, nationally. This ranged from 1.5 °C to 4.9 °C in VIC and NSW, respectively. Synthetic turf – short pile for this study was defined as shorter, synthetic carpet like surfaces found in older synthetic yard coverings and cricket nets as they are easily distinguishable in aerial imagery. The lower mass of these surfaces may limit the total amount of heat they retain even though they provide a consistent warming.

Bitumen, included as a control, consistently fell between synthetic turf – long pile and synthetic turf – short pile, providing a 4.8 °C warming influence nationally, and ranging from 3.7 °C warming in SA to 6.3 °C warming in NSW.

The urban heat island effect is driven primarily by the change from natural to built landscapes, replacing light coloured, low density, porous materials with dark, dense, impervious surfaces. The analysis of the thermal performance of these five landscape coverings reinforce this pattern, as natural materials provide a cooling influence in 84% of the examples investigated, while built materials provided a warming influence in 82% of the examples.

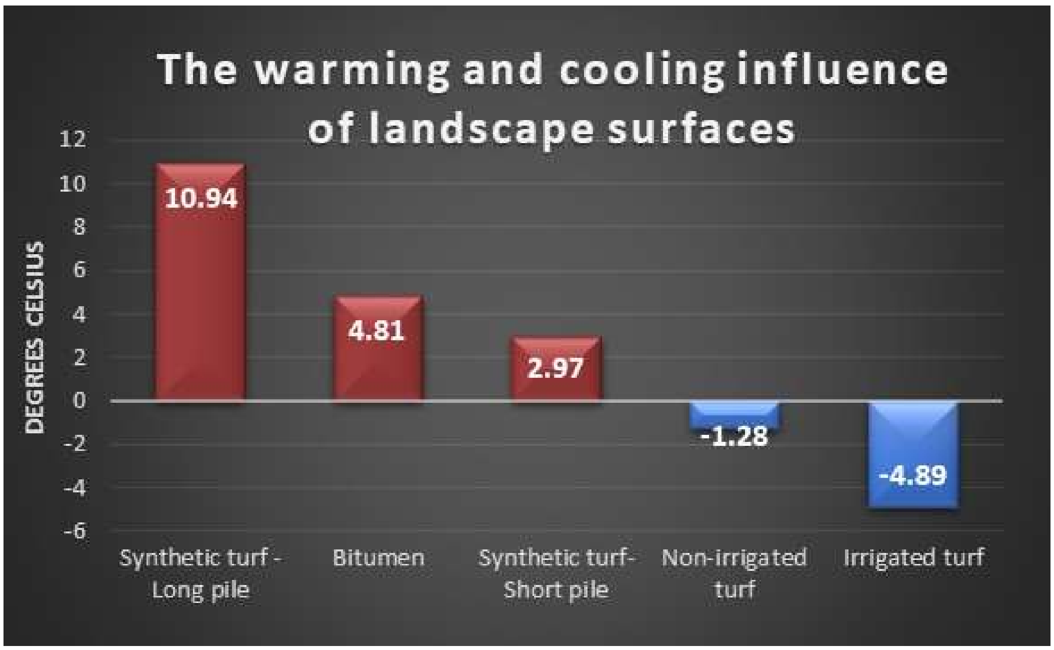


Figure 2. The thermal performance of landscape surfaces based on combined observations in Adelaide, Melbourne and Sydney.

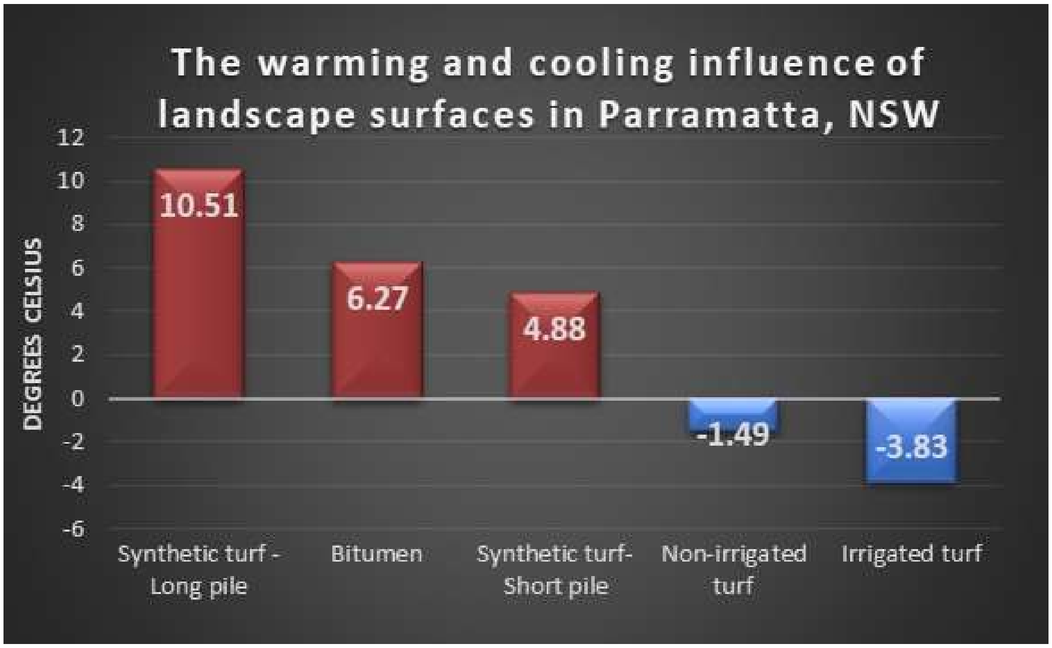


Figure 3. The thermal performance of landscape surfaces in the City of Parramatta, NSW.

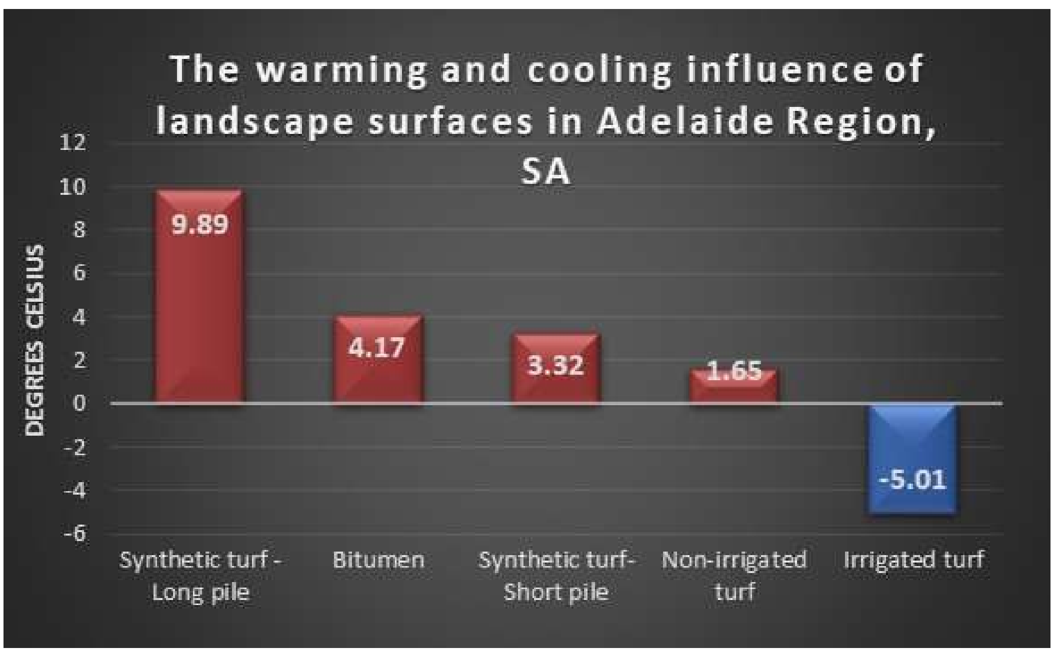


Figure 4. The thermal performance of landscape surfaces in Western and Eastern Adelaide, SA.

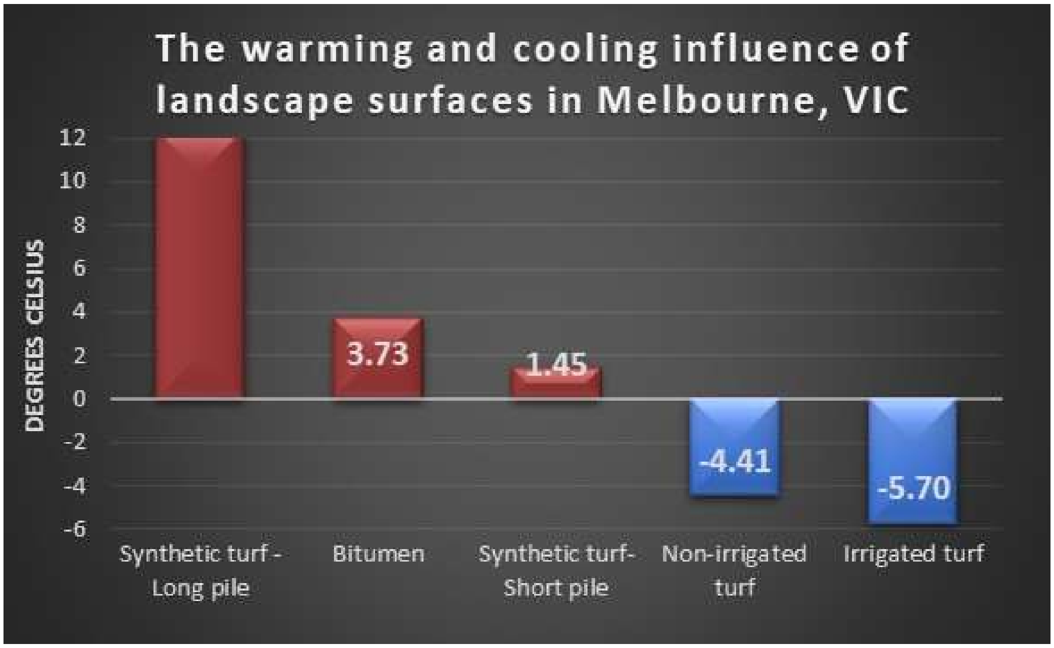


Figure 5. The thermal performance of landscape surfaces in the Cities of Melbourne and Port Phillip, VIC.

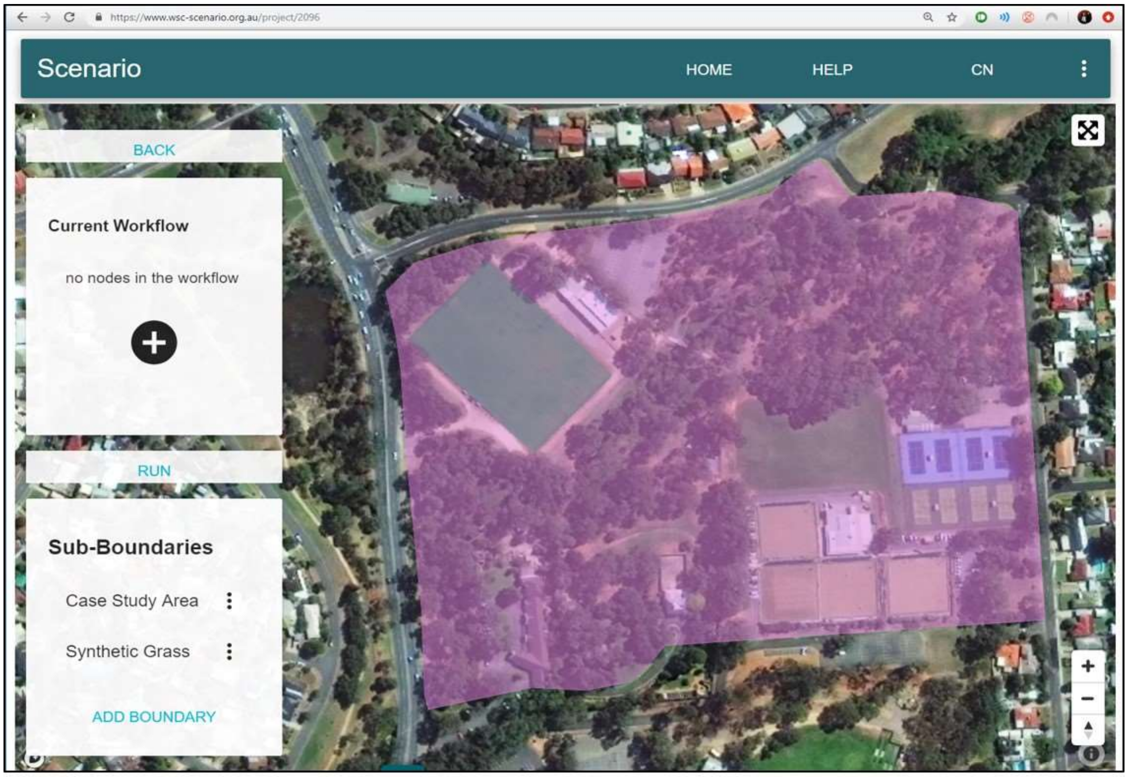
2.4 Modelling the impact of land surface change

The differences in land surface temperature observed over various surfaces raises the question of, “how do large scale planning changes affect broader urban heat and heat islands?”, and more specifically, “how does the choice between natural and synthetic grass influence the temperatures of the surrounding area?”. The Cooperative Research Centre (CRC) for Water Sensitive Cities has developed a series of modelling tools, including the Extreme Heat Assessment Tool that is currently in beta testing, to understand the role of changing land uses in contributing to urban warming.

Using the Extreme Heat Assessment Tool, a demonstration case study was developed to investigate the area surrounding the Smith Partners Stadium in the Metro Adelaide region. Smith Partners Stadium features a soccer pitch that was changed from irrigated living grass to synthetic grass in 2017, and is set within a broader forested area comprised of trees, non-irrigated living grass, irrigated living grass for lawn bowls, tennis courts, and several buildings and parking lots. The soccer pitch covers 0.88 hectares of the broader 13.6-hectare area, equating to 6.5% of the land cover.

Two scenarios were analysed using the CRC tool: 1) a baseline scenario modelling the soccer pitch as irrigated living grass, and 2) a synthetic grass scenario modelling the soccer pitch resurfaced with synthetic grass (Figure 6). The CRC tool has seven designated land use classifications. Synthetic grass was modelled as a mix of concrete and bitumen surfaces which produced an equivalent warming signal of 15.83 °C warmer than irrigated living turf which is the relationship identified in the land surface temperature assessment (Section 2).

Over the soccer pitch itself, replacing living irrigated grass with synthetic grass would have caused surface temperatures to increase by 15.83 °C. Modelling this within the CRC tool however, suggests that the switch to synthetic grass increases the average surface temperature of the broader 13.6 hectare area by 1.06 °C (Figure 7 and Figure 8).



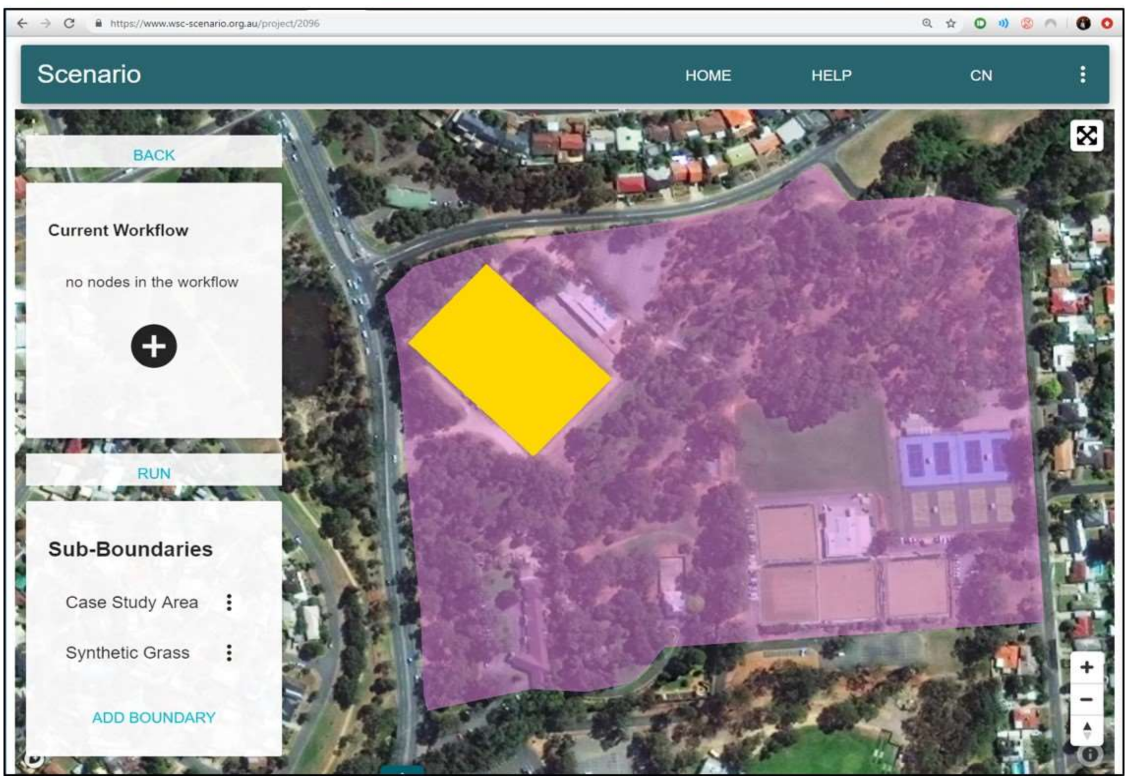


Figure 6. CRC Extreme Heat Assessment Tool highlighting the Smith Partners Stadium and surrounds. Yellow indicates sports field replaced with synthetic grass in 2017.

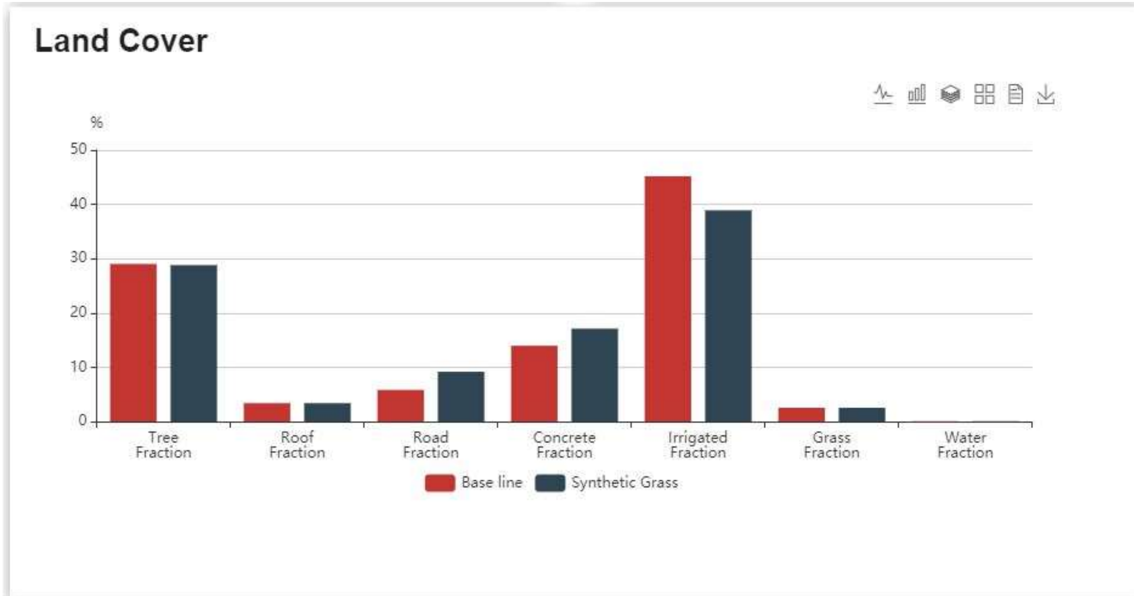


Figure 7. Landcover fractions identified under the baseline and synthetic grass scenarios.

Land Surface Temperature

Scenario	Average Surface Temp... °C
Base line	41.99
Synthetic Grass	43.05

Figure 8. Overall land surface temperatures under baseline and synthetic grass scenario.

2.5 Limitations

This assessment provides a broad categorisation of landscape surfaces into five groups to coarsely identify general, average differences in thermal performance. Using more specific subsets of surface types—i.e. specific manufactured types of synthetic turf, or living turf irrigated nightly versus twice weekly— may yield more specific results, however, this would likely limit the number of examples within each category reducing robustness of the results. While this investigation provides a significant number of (1,580) measurements, additional measurements will further refine results. Additional assessments using different land surface datasets will improve insights into the drivers of land surface temperature.

Due to the high number of examples, the landscape feature types were visually identified from aerial imagery, usually using imagery acquired at the same time as thermal data. However, some mismatches in dates may lead to misclassification of feature types. The large number of examples reduces the sensitivity of this analysis to such risk. Furthermore, the differences in thermal dataset resolution may lower the accuracy of the assessment, specifically of the smaller features, such as many of the synthetic turf – short pile examples.

Within the Adelaide region, two land surface temperature datasets were included from the West Adelaide Region and Eastern Adelaide Region, collected in 2017 and 2018, respectively. These seasons contrasted in their precipitation, with 2017 being a wet summer and 2018 being a dry summer. Due to the variation in annual conditions, non-irrigated natural turf provided a warming influence one year and a cooling influence the following year, making its long-term influence highly variable.

Due to errors that existed in the original dataset provided to the project team, the City of Melbourne data underwent considerable reprocessing and reclassification in generating the land surface temperature data[1]. In that dataset, synthetic turf surfaces, which are visually difficult to differentiate from irrigated living turf, appear to have been misclassified as they had a high correlation with irrigated living turf and did not group with synthetic turf in other states. As such, synthetic turf – long pile surface temperature data was excluded from the City of Melbourne dataset, so the synthetic turf – long pile surface temperature results are only from the City of Port Phillip data.

[1] This was prior and separate to the analysis conducted as part of this study.

3 Surface-to-air relationship assessment

3.1 Context

There are two types of heat important in understanding drivers of thermal comfort: surface temperature and air temperature. Surface temperature (assessed in Section 2) has a major influence on air temperature, but air temperature is also influenced by land surfaces surrounding a given point. Additionally, thermal comfort, or *how humans experience temperature*, is also affected by relative humidity, wind, and other local climatic conditions.

To incorporate these aspects into the analysis, an air temperature assessment was conducted to measure the influence of living turf (henceforth referred to as living turf) on thermal comfort across a range of environments and climates, focusing on the boundaries where irrigated living turf encounters other landscape types: bitumen, bare ground, playing courts, non-irrigated turf, and synthetic turf – long pile. In these locations, a temperature sensor array was deployed along a transect to measure the air temperature, surface temperature, and thermal comfort over a span of 8 meters (Figure 9).

By comparing the air temperature profile with the land surface temperature profile over a range of surface types, the range of influence and the magnitude of cooling specifically attributed to living turf was assessed, providing a direct measure of the effectiveness of living turf in mitigating urban heat islands. The thermal comfort was then assessed over each land surface type in each of the three States, to discern potential variations to those relationships for specific climates. The range and magnitude of the thermal influence informs the thermal impact modelling.

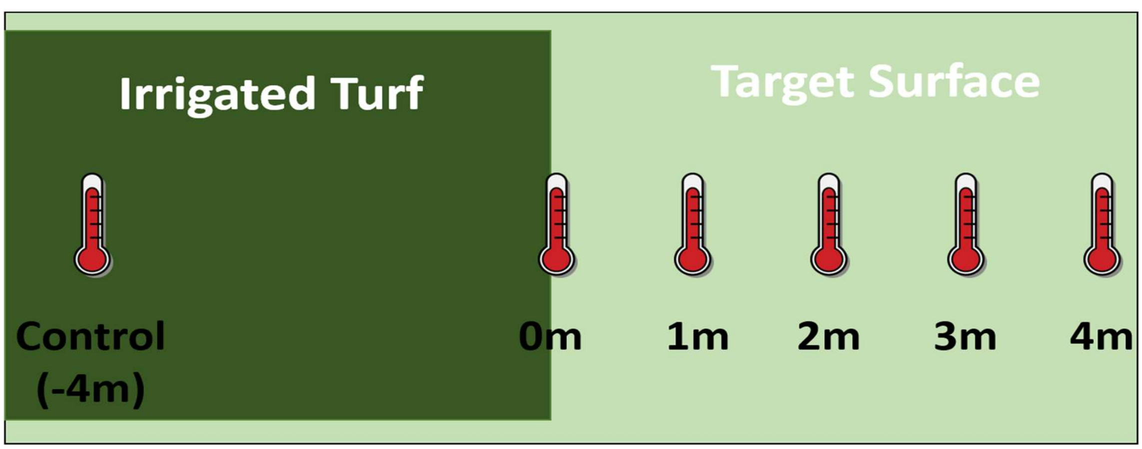


Figure 9. Illustration of transect for measuring air temperature, thermal comfort, and land surface temperature.

3.2 Methods

A temperature sensor array consisting of six Kestrel Heat Stress Weather Sensors (models 4400 and 5400) was deployed on tripods at a height of 1.2 m to measure the climatological variables across the transition from irrigated living turf to other various surfaces. In each of the three areas where land surface temperature maps were acquired (Adelaide, SA; Port Phillip and Moreland, VIC; and Parramatta, NSW), the sensor array was deployed over the five land surface types for a period of roughly 1 hour each. These assessments were undertaken on hot days (greater than 33 °C) that were preceded by at least one warm day (greater than 30 °C) to allow the landscape to warm thoroughly. These conditions were met on February 2nd, 2019 in Adelaide (Figure 13), February 3rd, 2019 in Melbourne (Figure 11, Figure 12), and February 12th, 2019 in Parramatta (Figure 10). BOM forecast maximum temperatures for these days were 36 °C, 39 °C, and 37 °C, respectively. All measurements were taken during the hottest period of the day between 11 am and 4 pm.

Sensors were deployed directly over the surface transition and at 1 m intervals (up to 4 m) over the target surface to capture the range of influence over which irrigated living turf provides a cooling influence. Additionally, a sixth control sensor was deployed 4 m into the irrigated natural turf. Preliminary data collected in Adelaide on December 6th, 2018 suggested the range of influence over living turf to be somewhere in the 2-3 m range, hence guiding the transect length of 4 m.

Figure 10. Playing court example from Parramatta, NSW (12 Feb 2019).

Figure 11. Synthetic turf example from Port Phillip, VIC (03 Feb 2019).

Figure 12. Non-irrigated natural turf example from Port Phillip, VIC (03 Feb 2019).

Figure 13. Bare ground example from Adelaide, SA (02 Feb 2019).

Table 2. Land feature types included thermal comfort assessment.

Surface type	Description	Examples
Non-irrigated living turf	Areas of maintained vegetation with no evidence of irrigation	Reserves, sports fields surrounds,
Bare ground	Barren areas of dirt, woodchips, gravel	Reserves, construction areas,
Synthetic turf – long pile	Large fields of synthetic turf playing surfaces directly adjacent to irrigated turf	Hockey clubs, futsal fields
Playing courts	Tennis/netball courts	Playgrounds, parks,
Bitumen	Dark hardscaped parking lots in areas with limited traffic	Parking lots

In addition to assessing air temperatures for each transect, thermal comfort was also assessed by calculating Universal Thermal Climate Index (UTCI) values at each station. UTCI incorporates air temperature, radiative temperature (influence of direct sunlight), relative humidity, and wind speed in calculating the apparent temperature humans feel in those conditions, given in terms of degrees Celsius (Figure 14). For each of the six stations on the transect, UTCI values were calculated according to the equations given in (Blazejczyk et al. 2013). UTCI values are intended to factor in the broader weather conditions to allow thermal comfort to be assessed in a single number.

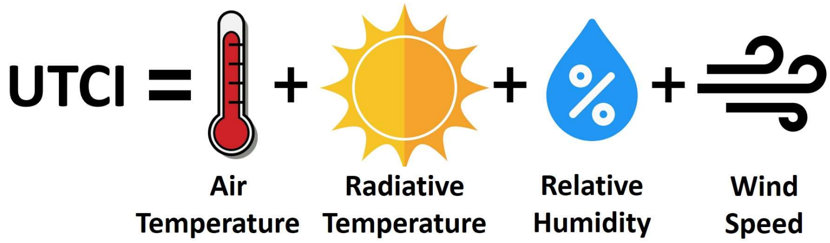


Figure 14. Conceptual equation of the Universal Thermal Climate Index (UTCI).

3.3 State results

3.3.1 New South Wales

Data collection in Parramatta, NSW took place on February 12th, 2019, which was the 10th hottest day of the 2018/2019 summer season (BOM Parramatta). The high temperatures were accompanied by high winds which exceeded 7 m/s at times during the day of collection. The excessive wind occasionally blew down the lightweight sensors causing the older sensors to lose power and erase their data. The stations that suffered data loss were positioned at non-critical points in the transect, allowing the analysis to still be conducted, though with reduced number of weather stations.

Transects were deployed over non-irrigated living turf, bare ground, and bitumen at George Kendall Reserve between 11:00 am and 2:00 pm, and the playing court and synthetic turf West Epping Park between 3:00 pm and 4:30 pm.

Irrigated living turf versus non-irrigated living turf

Surface temperatures across the non-irrigated transect increased by 16.5 °C as compared to the irrigated living turf control (Figure 15). Over this same area, air temperatures increased 1.4 °C at the 3 m mark, then dropped back to only 0.1 °C warmer at the 4 m mark. Maximum air temperatures at the 3 m mark were 7.3 °C warmer than the maximum air temperature at the control site, attained during a calm period in the otherwise high wind conditions which exceeded 7.3 m/s. Average thermal comfort values at 3 m were 1.9 °C above the control value.

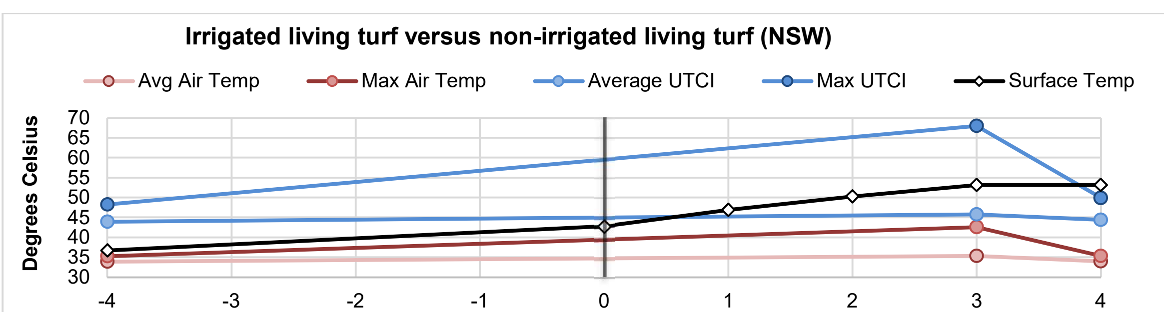


Figure 15. Results of NSW non-irrigated living turf thermal assessment.

Irrigated living turf versus playing court

Surface temperatures across the playing court transect rose quickly over the target surface reaching a peak value of 62.2 °C at the 1 m mark, nearly 28 °C above the irrigated living turf control surface (Figure 16). However, average air temperatures were all equal across the transect measuring 36.5 °C. UTCI increased slightly over the target surface measuring 0.4°C warmer than the control at the 4 m mark.

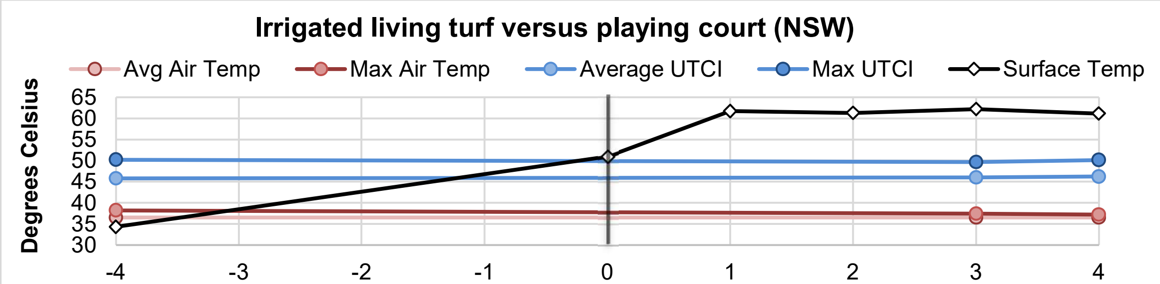


Figure 16. Results of NSW playing court thermal assessment.

Irrigated living turf versus bitumen

The bitumen transect showed a warming of 27 °C between the irrigated living turf and target surface (Figure 17). Surface temperatures rose quickly over the first meter of the target surface and then remained relatively stable over the rest of the transect. Average air temperatures increased by 1.3 °C at the 3 m mark, where the maximum temperature was 5.9 °C warmer than the control. Average UTCI increased by 1 °C over the target surface, and maximum UTCI was found to be 2.5 °C warmer than the control.

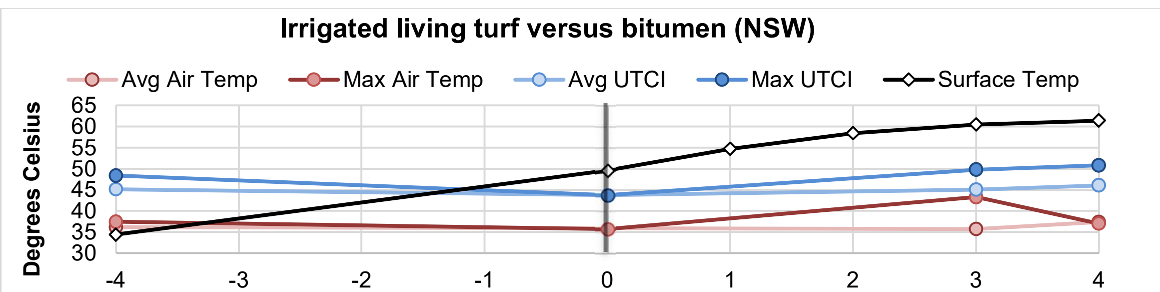


Figure 17. Results of NSW bitumen thermal assessment.

Irrigated living turf versus synthetic turf

Surface temperatures increased dramatically over the synthetic turf raising 23 °C by the 2 m mark (Figure 18). Average air temperatures only rose 0.4 °C over that corresponding transect. However, maximum air temperatures were 2.0 °C warmer over the synthetic turf as compared to the irrigated living turf. UTCI values warmed by less than 1 °C over the target surface. Both air temperatures and UTCI values were collected in conditions with maximum wind speeds of 4.8 m/s.

To further investigate the transfer of surface temperature to air temperature, a near-ground air temperature sensor (Kestrel D3-Fire) was also deployed suspended under the 4 m sensor, 10 cm above ground level, out of direct sunlight. Near ground air temperatures averaged 40.5 °C, 4.5 °C warmer than the living turf control, and the maximum temperature reached 42.4 °C, almost 6 °C warmer than the control. This additional data point further suggests that the transfer of surface heat into air temperature is considerably larger than is observed at the 1.2 m height due to mixing of the air column. As such, it is suspected that exceedingly warm surfaces are substantially contributing to air temperature warming but that the effect is distributed over a larger area than anticipated, hence the weaker-than-anticipated signal in air temperature increases.

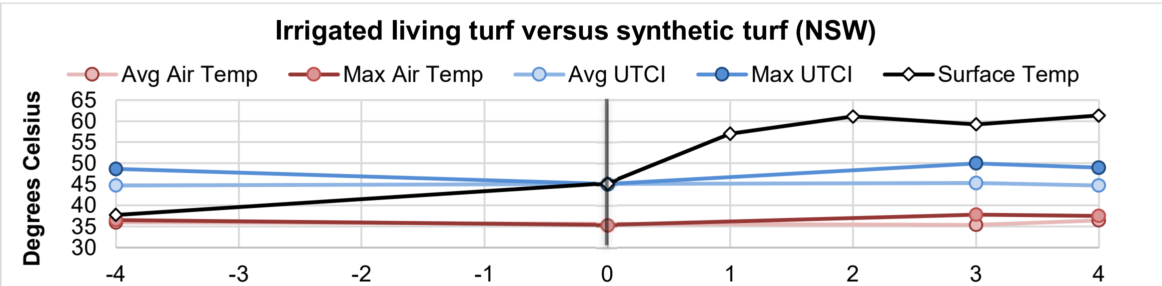


Figure 18. Results of NSW synthetic turf thermal assessment.

<u>Irrigated living turf versus bare ground</u>

In the bare ground transect, surface temperatures increased by 14 °C, reaching the peak value at the 1 m mark and remaining within 1 °C of the maximum temperature across the remainder of the target surface (Figure 19). Average wind speeds during this transect were 3.8 m/s and reached maximum wind speeds of 7 m/s. As such, the air column was well mixed and average air temperatures were all within 0.1 °C across the transect. Average UTCI values were also all within 0.1 °C across the transect.

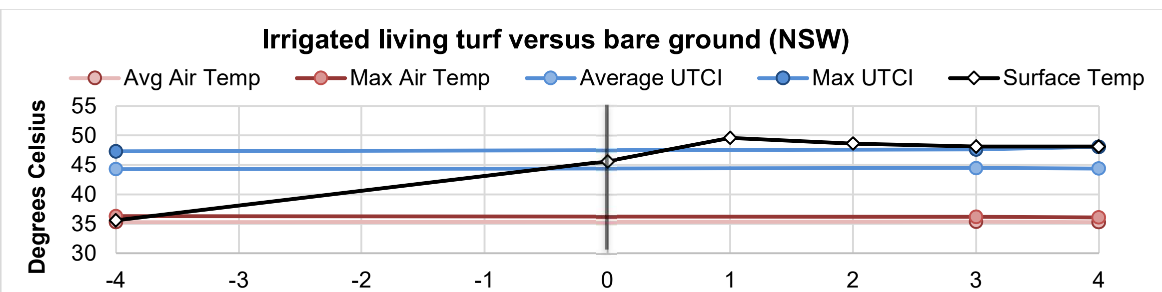


Figure 19. Results of NSW bare ground thermal assessment.

<u>Surface temperature across surface materials</u>

Across the NSW transects, surface temperatures increased substantially over the target surfaces (Figure 20). Playing courts, synthetic turf, and bitumen were found to have maximum temperatures between 23 and 28 °C warmer than irrigated living turf. Bare ground and non-irrigated living turf were not as hot, but still registered maximum surface temperatures of between 14 and 17 °C warmer than irrigated living turf.

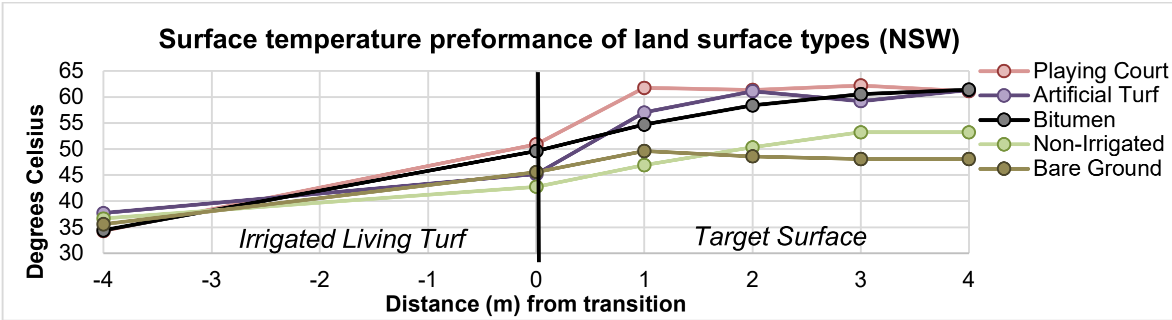


Figure 20. Surface temperature results of NSW thermal assessment.

Air temperature across surface materials

Differences in air temperatures were much less pronounced than changes in surface temperatures with the maximum average warming of 1.4 °C found at the 3 m mark over non-irrigated living turf (Figure 21). Bitumen had a similar warming of 1.3 °C at the 3 m mark, while all other average air temperatures were within 0.6 °C of the living turf control. All five transects in NSW encountered peak wind speeds in excess of 3.8 m/s.

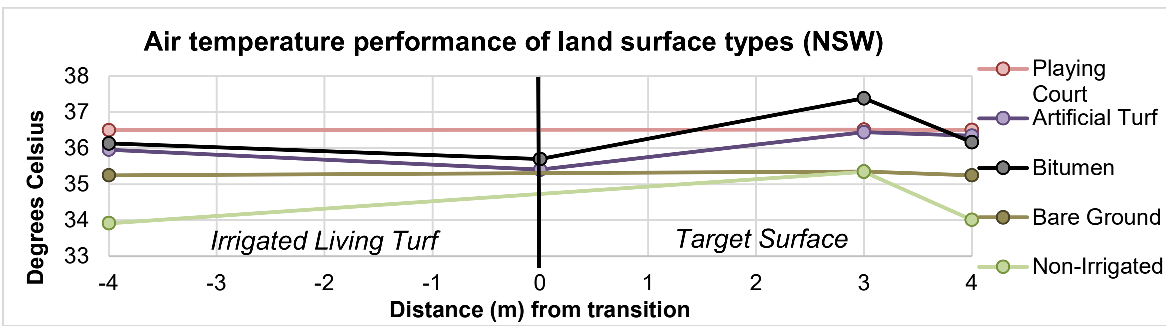


Figure 21. Air temperature results of NSW thermal assessment.

UTCI across surface materials

Average UTCI values all fell within a range of 2.3 °C (Figure 22). These values were found to increase over the target surfaces by between 0.2 °C over bare ground, to 1.9 °C over non-irrigated living turf. Conditions along the bare ground transect were nearly identical at all stations and for all 4 UTCI variables. In the non-irrigated natural turf transect, over the target surface both air temperature and radiative warming increased leading to the higher UTCI score. Bitumen's low UTCI score at the 0 m mark was driven by a lower air temperature at that location.

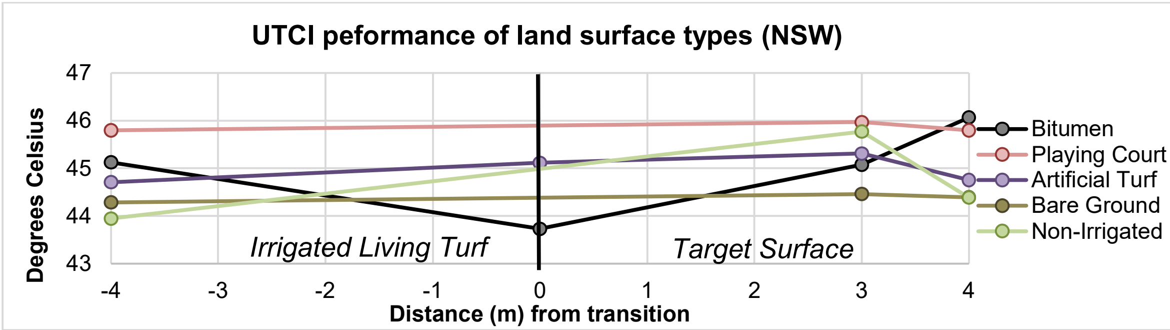


Figure 22. Universal Thermal Comfort Index (UTCI) results of NSW thermal assessment.

3.3.2 South Australia

South Australian data were collected at Adelaide High School on Feb 2nd, 2019, deploying the sensor arrays over the five target surfaces between 10am and 3pm.

<u>Irrigated living turf versus non-irrigated living turf</u>
In the non-irrigated living turf transect, surface temperature measured 36.8 °C over the living turf control reaching a max of 51.5 °C at 3 m beyond the transition to non-irrigated living turf (Figure 23). With such a pronounced surface temperature difference of almost 15 °C, air temperatures were expected to follow a similar pattern. However, air temperatures rose less than 1 °C between the irrigated living turf and non-irrigated living turf.

Thermal comfort, as measured by the Universal Thermal Climate Index, followed a similar pattern of increasing to the 1 m mark, then decreasing to within 0.1 °C of living turf temperatures by the 3 m mark. This result is driven by the presence of a slight wind which greatly mixes the air column, suggesting that each air temperature sensor records an aggregated, averaged result representing a larger area than the individual point locations.

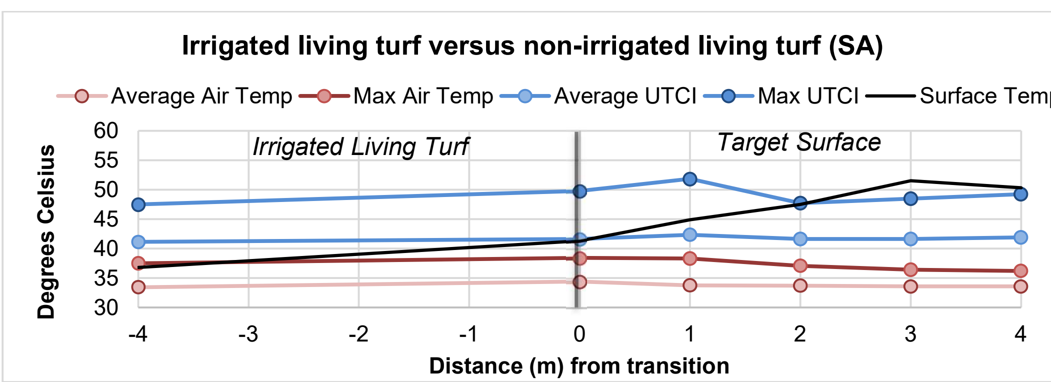


Figure 23. Results of SA non-irrigated living turf thermal assessment.

<u>Irrigated living turf versus playing court</u>
Exploring the interaction between living turf and playing courts in SA revealed a more nuanced relationship (Figure 24). The playing court surface temperature averaged 5 °C

warmer than the living turf control surface demonstrating the same relationship observed in the non-irrigated example. However, air temperatures also increased over the playing court following the expected pattern of air temperatures increasing with surface temperature, albeit only creating a 0.7 °C air temperature increase, reaching its full influence at the 2 m mark. The pattern was most pronounced in the maximum air temperature which was 1.4 °C warmer than the living turf. This pattern, although small in magnitude is consistent across the 2 m, 3 m, and 4 m sensors.

Wind speeds during this example were lighter and less consistent than in the non-irrigated example allowing the surface to warm the air in proportion to the different heat of the surfaces. These inconsistent winds also produced inconsistent UTCI measures which did not show a consistent pattern in this example.

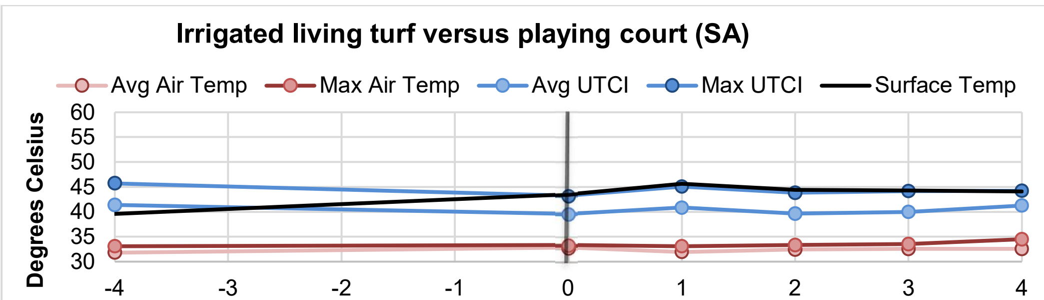


Figure 24. Results of SA playing court thermal assessment.

<u>Irrigated living turf versus bitumen</u>
The surface temperature of bitumen measured nearly 15 °C warmer than the living turf over the 8 m transect in SA (Figure 25), however, the air temperature sensors did not show a consistent signal with peak temperatures occurring at the transition followed by irregular measurements over the bitumen surface. UTCI measurements were also inconsistent.

The site selected for the bitumen-living turf transect in SA was approximately 5 m away from the corner of a building which created complex wind patterns (averaging 1.4 m/s). These winds appear to have diffused the surface signal before it could translate into a clear air temperature signal at this time and location.

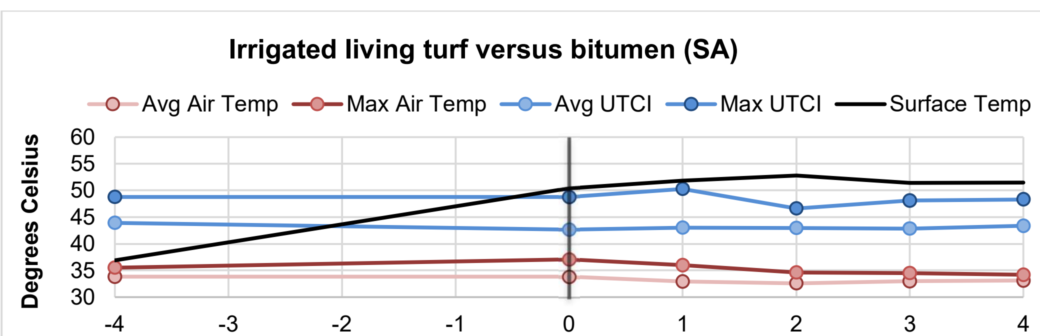


Figure 25 Results of SA bitumen thermal assessment.

Irrigated living turf versus synthetic turf

The SA synthetic turf transect confirmed the extreme surface temperatures of synthetic turf observed in the land surface temperature assessment. Additionally, the higher resolution of the hand-held thermometer (0.3 m) revealed local hot spots in excess of 70 °C (Figure 26). Air temperatures over this transect mirrored the land surface temperature pattern with average air temperatures of 1.4 °C warmer than living turf, and maximum air temperatures measuring 3.3 °C warmer than living turf. Maximum relative humidity was 5% lower over the synthetic turf demonstrating the lack of evapotranspiration over impervious surfaces. Maximum UTCI values measured 2.6 °C hotter at the 1 m mark than over living turf.

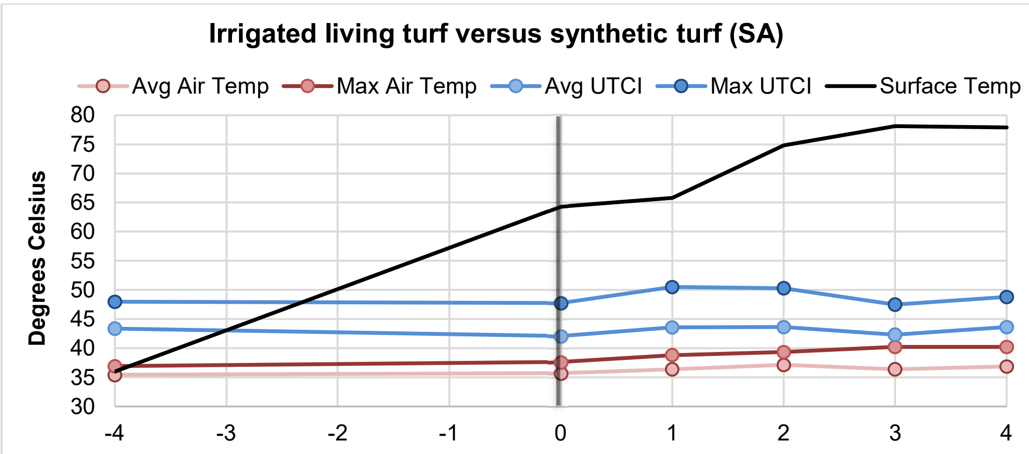


Figure 26. Results of SA synthetic turf thermal assessment.

Irrigated living turf versus bare ground

The surface temperature of the living turf control station (-4 m) measured 50 °C which matches more closely to the signal of non-irrigated living turf than to the other irrigated living turf controls (Figure 27). Most plausibly, the control site was set up over non-irrigated living turf instead of irrigated living turf, resulting in a flatter-than-usual surface temperature profile. Surface temperatures over bare ground increased with distance away from living turf but only by 4 °C. Air temperatures and thermal comfort provided no consistent pattern and were all observed to vary up and down by less than 1 °C between stations on account of stronger winds.

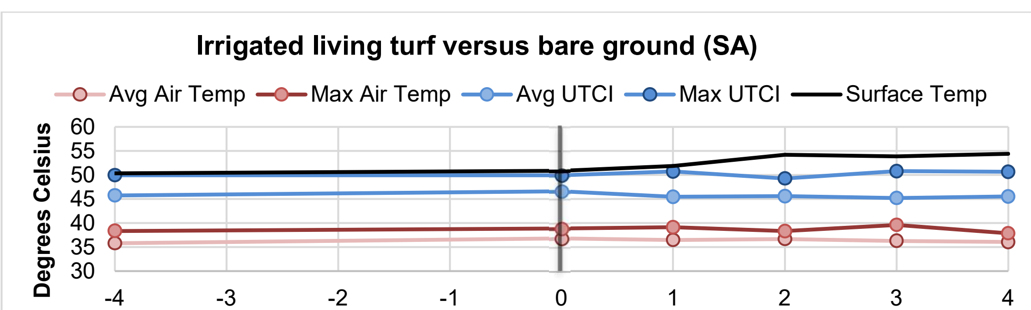


Figure 27. Results of SA bare ground thermal assessment.

Surface temperature across surface materials

All the surface temperature transects in SA reinforced the expected pattern of living turf providing the coolest surface temperatures and the target surfaces warming with distance away from the living turf (Figure 28). The magnitude of warming was in line with the results of the surface temperature assessment (Section 2) with synthetic turf providing the most extreme heating signal. The only anomaly was that the playing court measured 7 °C cooler than bitumen. The playing court in the South Australian transect was blue suggesting that the varying colours of playing courts may potentially have different thermal influences. Surface temperatures of the living turf control sites (excluding the bare ground example) remained consistent between 36 and 40 °C with peak temperatures of the target surfaces ranging between 45 and 78 °C.

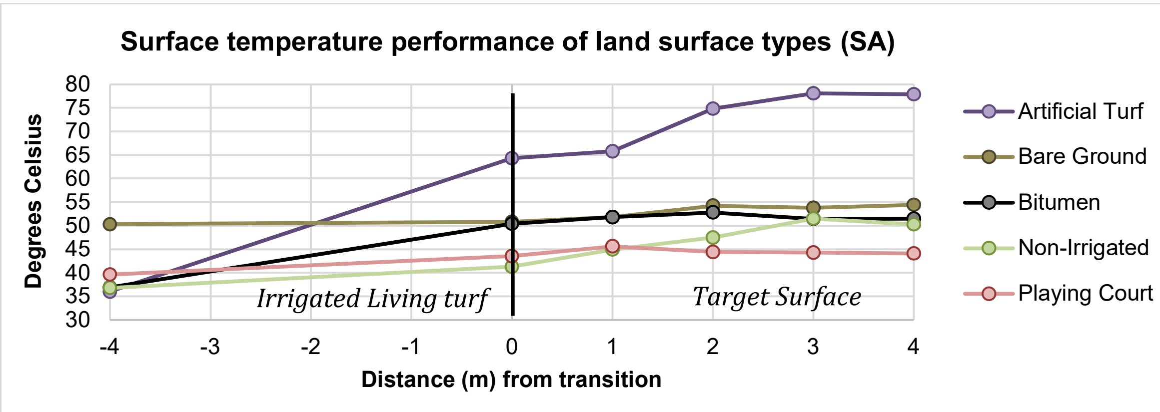


Figure 28. Surface temperature results of SA thermal assessment.

Air temperature across surface materials

Air temperatures in the SA case studies ranged from 32 to 37 °C across the five surfaces over the five-hour period of observation (Figure 29). All of these data are within several degrees of the BOM average at the time of collection, suggesting air temperatures are the product of a much larger area, much of which may lay beyond the range of the 8 m transect. Additional investigations into the scale of variation is needed. Furthermore, wind speeds of over 1m/s seem to be a critical threshold for the transference of surface temperatures into air temperatures with calmer winds allowing those patterns to be revealed, while stronger winds mix the air sufficiently to obscure any pattern.

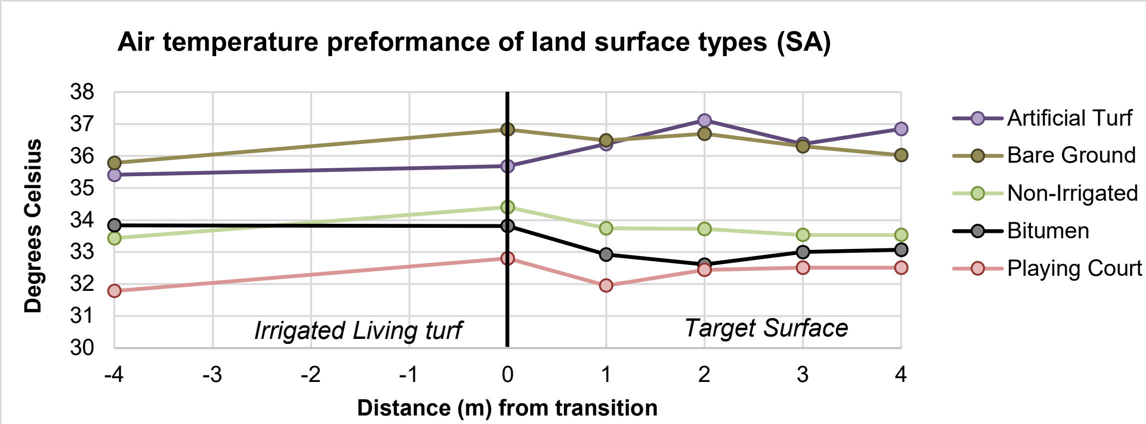


Figure 29. Air temperature results of SA thermal assessment.

<u>Thermal comfort across surface materials</u>

As the UTCI is heavily dependent upon air temperatures, a similarly inconsistent pattern of thermal comfort was found over the five target surfaces (Figure 30). Thermal comfort over living turf maintained a similar range to air temperature falling within 41 and 46 °C, but that range widened at the transition to the target surfaces, broadening to between 39 and 47 °C. Over the target surfaces, thermal comfort varied between 39 and 46 °C though exhibited weak patterns of increasing, and no clear pattern of UTCI values being elevated over the target surfaces as compared to the living turf control surfaces. While the target surfaces mainly demonstrated a slight increase in air temperature (particularly in calmer wind conditions) which increased the UTCI values, the impervious surfaces had lower relative humidity which decreased the UTCI values. These complex drivers of thermal comfort created an inconsistent pattern of UTCI values over the target surface types, owing to influences over an area broader than the study transect length.

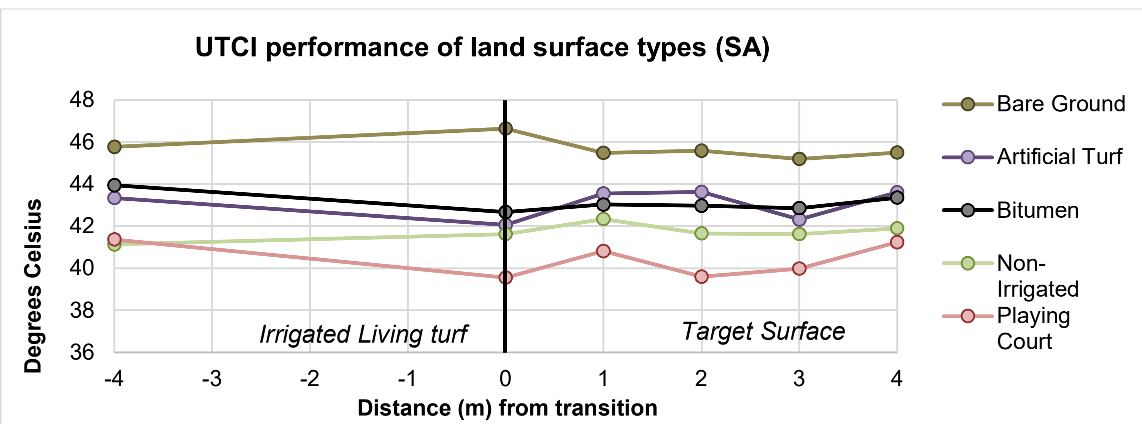


Figure 30. Universal Thermal Climate Index (UTCI) results of SA thermal assessment.

3.3.3 Victoria

Victorian data were collected on Feb 3rd, 2019, deploying the sensor transects over the five target surfaces between 11 am and 4 pm. The non-irrigated living turf, bitumen, and synthetic turf data were collected in Albert Park in the City of Port Phillip, and the playing court and bare ground data were collected in the City of Moreland.

Irrigated living turf versus non-irrigated living turf

In Port Phillip, the cooling influence of living turf compared with non-irrigated living turf was investigated at the edge of a well-manicured soccer pitch in Albert Park (Figure 12). Surface temperatures along this transect showed a consistent increase with distance away from the irrigated living turf increasing 8 °C over the course of the 8 m transect (Figure 31). Average air temperatures showed an increase of 2 °C, while maximum air temperatures showed a stronger increase of 6 °C. The warmer maximum air temperatures are assumed to be driven by momentarily lower wind speeds that allowed the surface heat to transfer into increased air temperatures directly above the target surface, whereas the average temperatures incorporate more wind-driven mixing which averaged 2.3 m/s during the deployment at this location. The high maximum UTCI measurements in this area were driven by high humidity (which averaged 68% at this location), on top of warm temperatures and strong radiative warming.

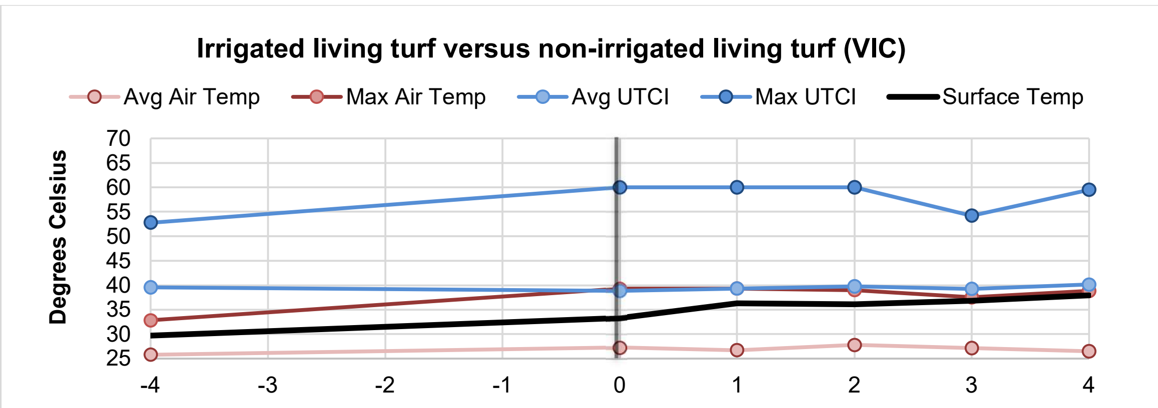


Figure 31. Results of VIC non-irrigated living turf thermal assessment.

Irrigated living turf versus playing court

The Victorian playing court transect displayed a strong and clear warming signal in the surface temperatures, exceeding 52 °C at the 1 m mark and reaching its maximum 54°C at the 3 m mark, more than 18.5 °C warmer than the living turf control temperature (Figure 32). Air temperatures averaged 1.7 °C warmer over the target surface, while maximum air temperatures were 4.4 °C warmer than the living turf control. UTCI was 8 °C warmer 1 m on to the playing court. The warming trends in the air temperature and the UTCI over the target surface was able to be resolved due to very calm wind conditions (averaged 0.4 m/s in this location).

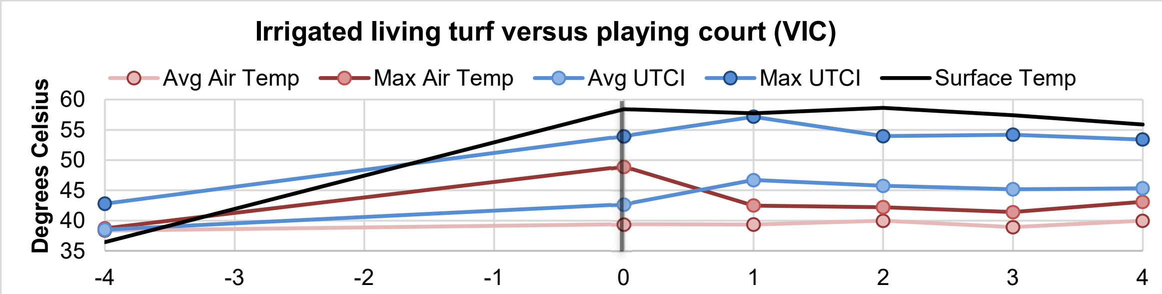


Figure 32. Results of VIC playing court thermal assessment.

<u>Irrigated living turf versus bitumen</u>
The bitumen transect in Victoria also demonstrated a clear warming pattern over the target surface increasing by over 17 °C at the 1 m mark (Figure 33). Air temperatures also increased by as much increasing by 2 °C at the 2 m mark. The 2 m sensor recorded the lowest wind speeds along the transect which correlated with the warmest readings; other sensors with higher winds had less consistent results. UTCI in this location was found to be 12 °C hotter than the air temperatures on account of the high relative humidity but results were variable from station to station due to the varying winds.

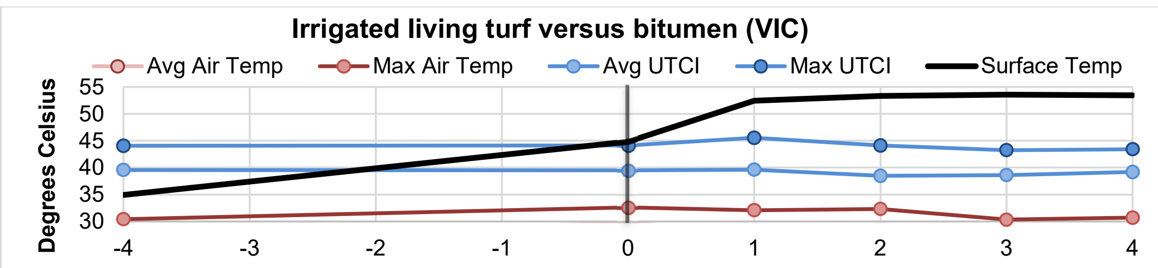


Figure 33. Results of VIC bitumen thermal assessment.

<u>Irrigated living turf versus synthetic turf</u>
Synthetic turf was the hottest surface measured in this part of the study, reaching surface temperatures above 70 °C (Figure 34). Surface temperatures were more than 30 °C warmer than the irrigated living turf control 4 m away from the synthetic turf. Air temperatures mirrored this pattern reaching 1.9 °C warmer than living turf at the 2 m mark, despite wind speeds averaging 1.5 m/s. Average UTCI values decreased slightly over the surface due to decreasing humidity, though maximum UTCI values showed no clear pattern.

In addition to the tripod mounted sensor recording temperatures at 1.2 m above the ground, an additional sensor was deployed at this location to record near-ground air temperatures. In this instance, a Kestrel D3 Fire sensor was suspended 10 cm above the synthetic turf under the 4 m sensor. The near-ground level air temperature was measured at 39.4 °C, 7.4 °C above the living turf control temperature and more than 5.9 °C warmer than the 1.2 m high sensor directly above. This suggests that a much stronger connection between surface and air temperature exists but it is quickly mixed into the broader air column by prevailing winds.

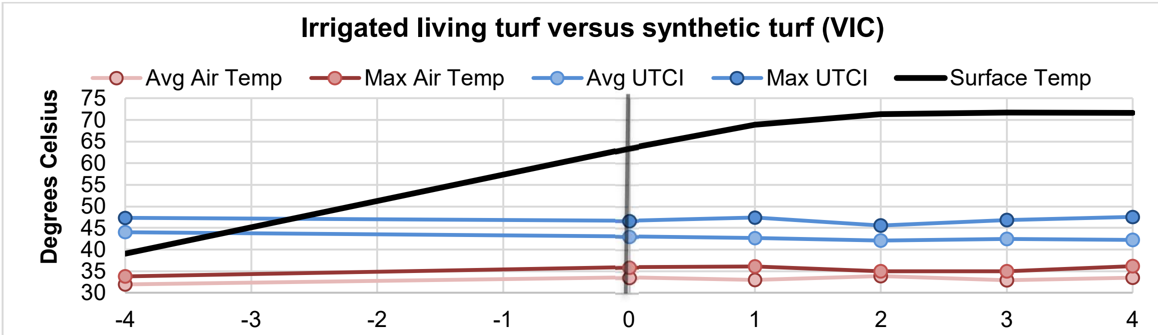


Figure 34. Results of VIC synthetic turf thermal assessment.

<u>Irrigated living turf versus bare ground</u>

Bare ground in Victoria was assessed in Raeburn Reserve in the City of Moreland. The surface temperatures increased by more than 11 °C at 1 m away from the irrigated living turf and reached a maximum value at 12.9 °C at the 3 m mark (Figure 35). Air temperatures showed a slight cooling over the transition from living turf to bare ground which appears to be driven by very high winds (exceeding 5 m/s at times). Conversely, UTCI showed a clear consistent heating over the target surface measuring 3 °C hotter than over the living turf due to strong radiative heating produced by the reflective bare ground surface.

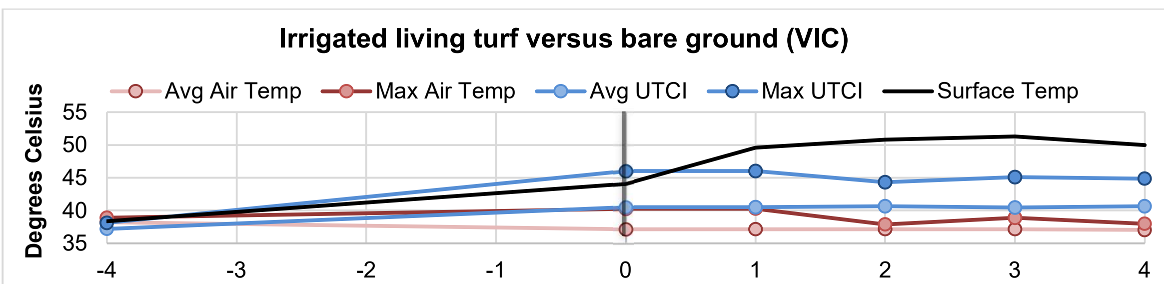


Figure 35. Results of VIC bare ground thermal assessment.

<u>Surface temperature across surface materials</u>

The surface temperature profiles collected across the Victorian examples illustrate the expected pattern of cooler irrigated living turf transitioning to the hotter target surfaces and reaching a temperature plateau as the effect of the irrigated living turf reaches the limit of its influence (Figure 36). Furthermore, the magnitude of the warming attributed to various surfaces confirms the relationships found in the land surface temperature assessment (Section 2) with synthetic turf being the hottest surface, followed by playing court, bitumen, bare ground, and finally non-irrigated living turf.

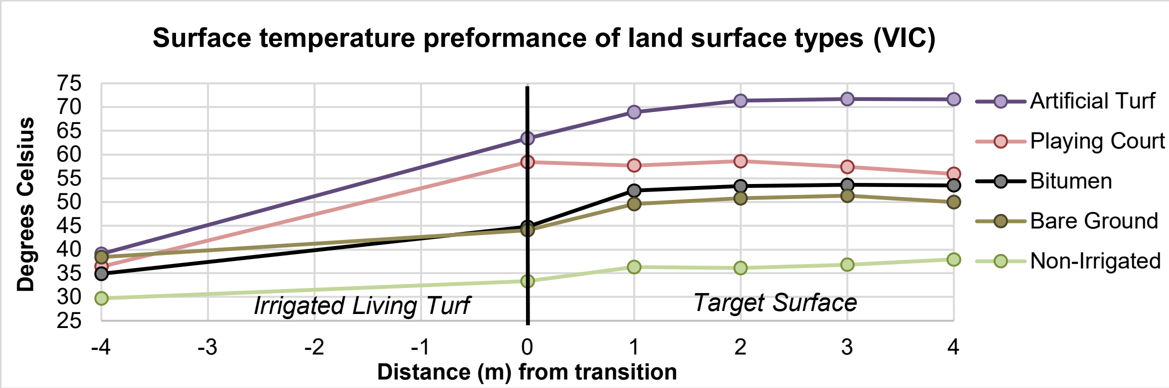


Figure 36. Surface temperature results of VIC thermal assessment.

<u>Air temperature across surface materials</u>

The air temperature patterns captured by the transects in Victoria were more consistent than in the South Australian data. Air temperatures over the target surfaces averaged between 1.2 and 1.4 °C warmer than the living turf controls in all transects except the bare ground example which had exceedingly strong winds (Figure 37). The strongest average warming signal was found over synthetic turf which measured 1.9 °C warming, over an extremely hot surface despite moderate winds. The second strongest warming signal occurred over the playing court, over a warm surface under very low winds.

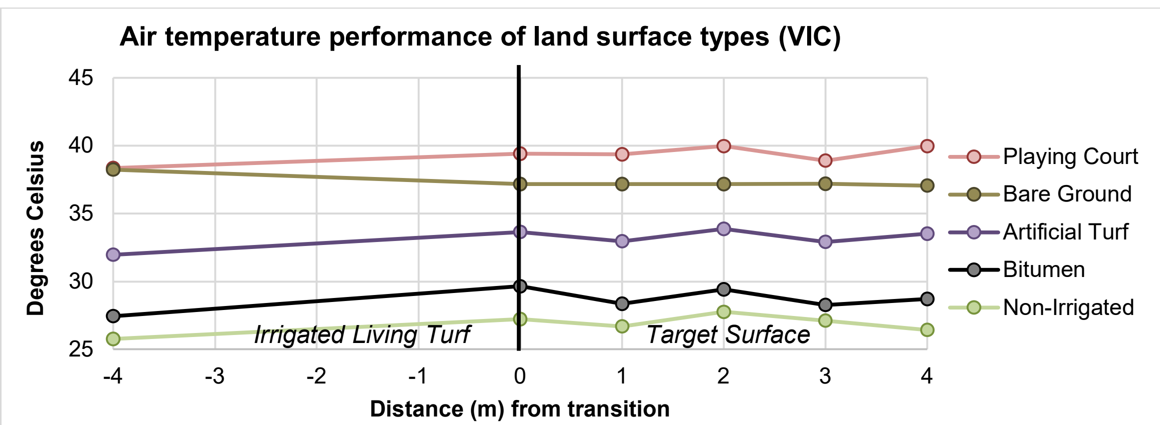


Figure 37. Air temperature results of VIC thermal assessment.

<u>UTCI across surface materials</u>

UTCI values in Victoria displayed highly varied results with three surfaces displaying strong warming trends over the target surfaces (non-irrigated living turf, playing court, and bare ground) and two providing generally flat trends (synthetic turf and bitumen) (Figure 38). The flat UTCI profiles found over the synthetic turf and bitumen transects are the result of high UTCI values at the natural turf control locations, which seem to correlate with higher wind speeds at the -4 m mark compared to the transect average. It is not clear why these sensors recorded higher wind speeds, but it is consistent throughout the full period of data collection at each site.

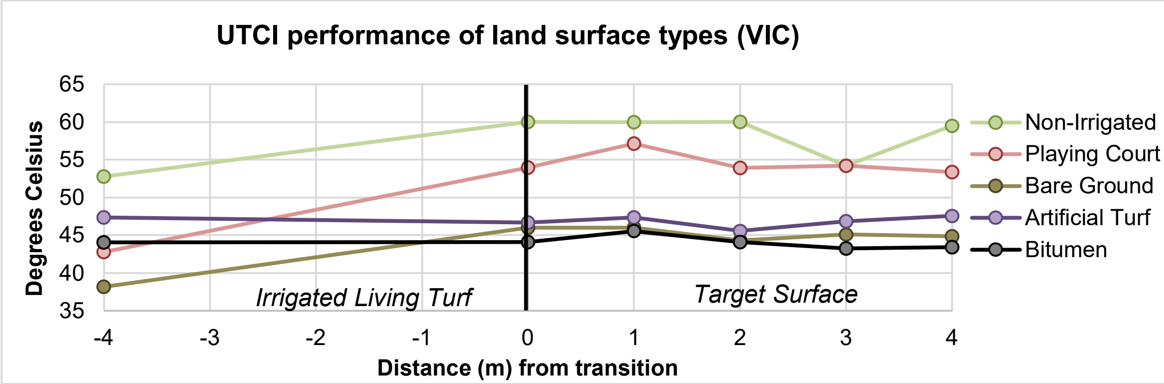


Figure 38. Universal Thermal Climate Index (UTCI) results of VIC thermal assessment.

3.4 National results

For each target surface, values from the three state transects were averaged to generate national averaged results for surface temperatures, air temperatures, and thermal comfort. The difference between surface temperature and air temperature is smallest over living turf and greatest over synthetic turf. At all 15 transects across the three states, surface temperatures were within 5 °C warmer than air temperatures over all the natural turf control sites (Figure 39 - Figure 43). Over the target surfaces, these temperatures diverge with synthetic turf showing a surface temperature more than 34 °C above air temperature (Figure 41). UTCI was found to be 8 °C above air temperature across all surfaces, on average (Figure 39 -Figure 43).

Irrigated living turf versus non-irrigated living turf

Average surface temperatures of non-irrigated living turf transects measured across Australia were found to reach 13 °C above the irrigated living turf surface temperatures by the 3 m mark, remaining constant through 4 m (Figure 39). Air temperatures, on average, increase by 1 °C by the 3 m mark as well. UTCI also reaches a peak at 3 m, though by a slightly smaller margin (0.7 °C).

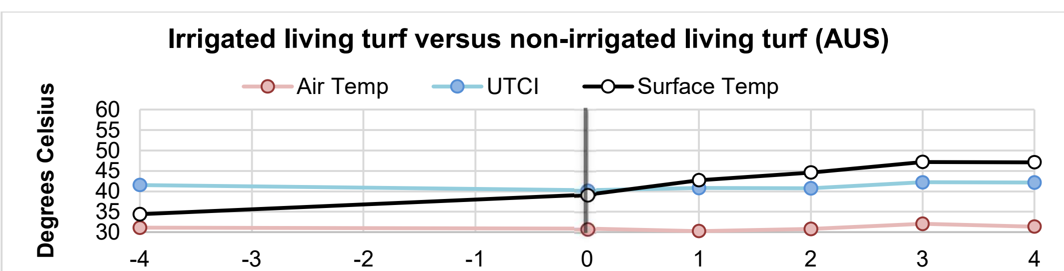


Figure 39. Results of national non-irrigated living turf thermal assessment.

Irrigated living turf versus playing court

Playing court surface temperatures were found to be 18 °C warmer than nearby irrigated living turf, reaching their peak temperatures at the 1 m mark and remaining within 2 °C of that peak surface temperature across the transect (Figure 40). Air temperatures rose by 0.8 °C by the 4 m mark. UTCI, on average, increased steadily across the transects reaching a peak of 2.3 °C warmer than irrigated turf by the 4 m mark.

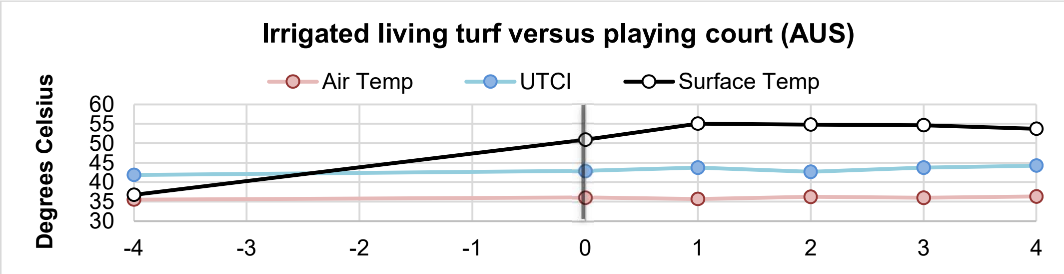


Figure 40. Results of national playing court thermal assessment.

<u>Irrigated living turf versus synthetic turf</u>
The surface temperatures of synthetic turf rose quickly across all three transects, increasing 20 °C at the transition, and increasing to over 30 °C by the 2 m mark (Figure 41). Air temperatures followed this pattern increasing, on average, 1 °C by the 4 m mark. UTCI presented mixed results with values decreasing slightly (0.4 °C) by the 4 m mark, likely due to decreased humidity.

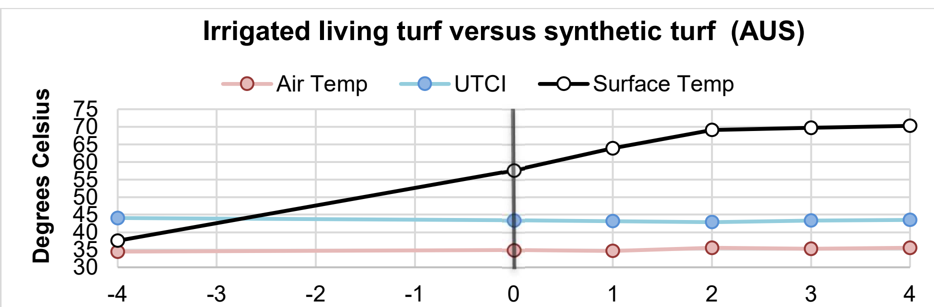


Figure 41. Results of national synthetic turf thermal assessment.

<u>Irrigated living turf versus bitumen</u>
Bitumen surface temperatures increased sharply jumping 20 °C by the 2 m mark and continuing to increase throughout the transects (Figure 42). Air temperature provided mixed results decreasing, on average, by 0.15 °C over the three transects. UTCI presented no change at the 4 m mark as compared to the living turf control.

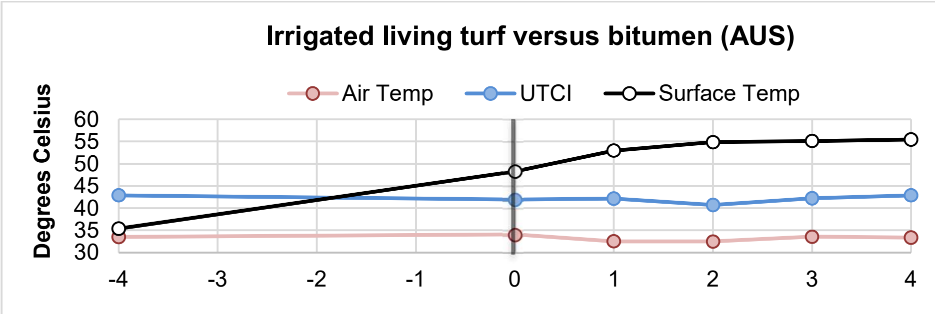


Figure 42. Results of national bitumen thermal assessment.

Irrigated living turf versus bare ground

The surface temperature of bare ground was shown to be 9 °C warmer than that of irrigated living turf, on average (Figure 43). Over the three transects, it reached and sustained this warming by the 1 m mark. Air temperatures varied, increasing by 0.5 °C at the transition, but then ultimately regressing to be slightly lower (0.3 °C cooler) than over the irrigated living turf. Despite this slight cooling in air temperature, UTCI values increased by 1 °C on average over the three transects.

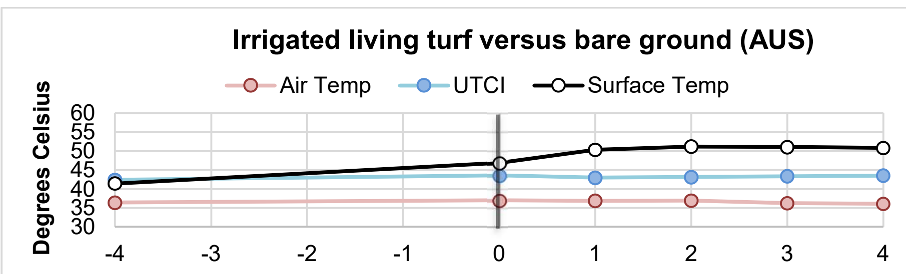


Figure 43. Results of national bare ground thermal assessment.

Surface temperature across surface materials

The surface temperatures across all 15 transects collected across the three states revealed a clear pattern of irrigated living turf being much cooler than the target surfaces (Figure 44). At all times during the three hot days of data collection, average surface temperatures over irrigated living turf remained between 34 and 42 °C. Temperatures over the target surfaces ranged from 42 to 70 °C, with synthetic turf being the hottest measuring between 25 and 33 °C hotter that irrigated living turf between the 1 and 4 m marks.

Bitumen and playing courts were the second and third hottest surfaces, measuring 20 °C and 18 °C warmer than irrigated living turf, respectively. Non-irrigated living turf and bare ground presented the smallest warming signals of the five surface types investigated, averaging 11 and 9 °C warmer than irrigated living turf on average, respectively. Natural materials (bare ground and non-irrigated living turf) averaged 10 °C warming over the target surface (between the 1 m and 4 m marks), whereas synthetic materials (playing court, bitumen, and synthetic turf) averaged 23 °C of warming.

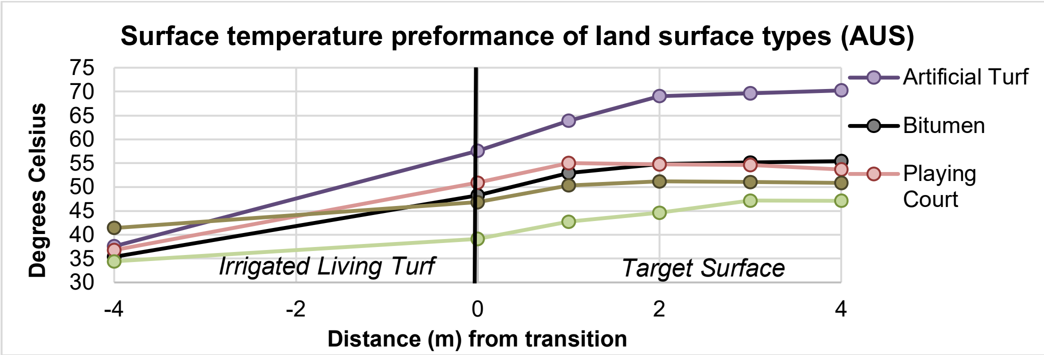


Figure 44. Surface temperature results of national thermal assessment.

Air temperature across surface materials

Air temperatures over the 15 transects showed an average maximum increase of 0.81 °C over nearby irrigated living turf (Figure 45). In general, air temperatures were very consistent across all surface types with average values measuring between 30 and 37 °C. Air temperature patterns over individual transects were highly varied.

Further analysis of air temperature data shows a strong negative correlation (correlation coefficient -0.80 in the South Australian data, -0.64 on average) between maximum air temperatures and wind speed, meaning that increased wind speeds diminish the maximum air temperatures recorded. Higher wind speeds produce more mixing of the air column and while the direct impact of surface warming is not dominant in the air temperature record, it suggests surface temperature influences warming over a larger area.

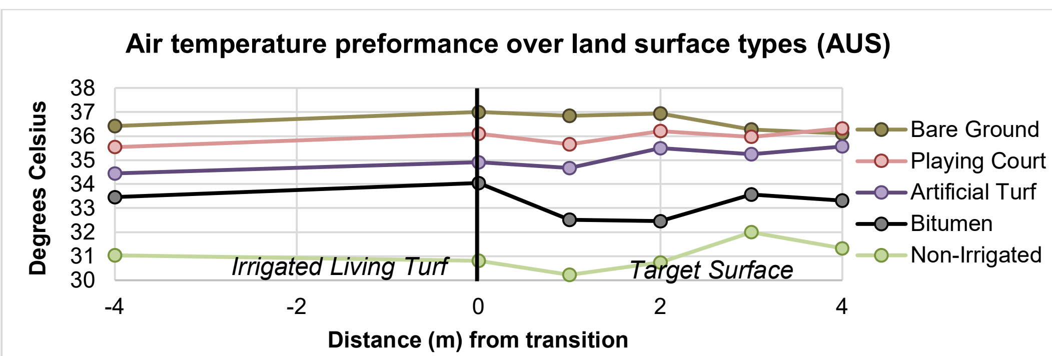


Figure 45. Air temperature results of national thermal assessment.

UTCI across surface materials

Average UTCI values were very consistent across the 15 transects ranging between 40 and 45 °C (Figure 46). On average, target surfaces (between 1 m and 4 m marks) were 0.3 °C warmer in thermal comfort values than the irrigated living turf. The overall patterns of UTCI across the transects were varied due to the sensitivity to each of the four UTCI input values, but the variation was small as the maximum range along any transect was less than 1 °C.

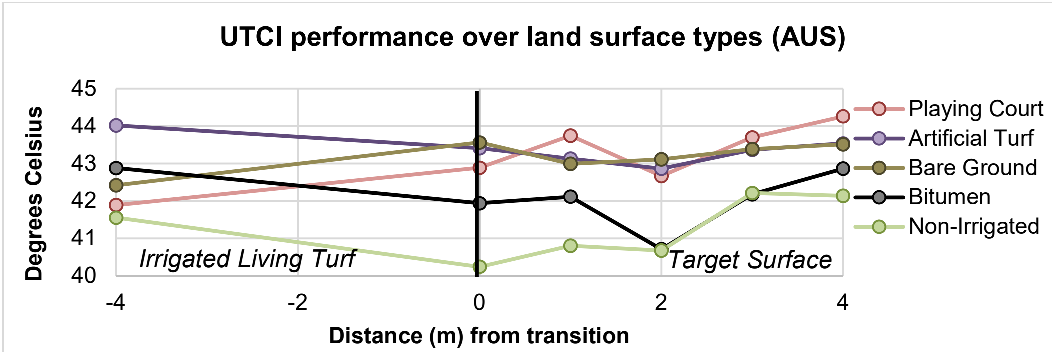


Figure 46. Universal Thermal Climate Index (UTCI) results of national thermal assessment.

3.4.1 Range of influence

A key metric explored in this portion of the study is the Range of Influence (RoI) which is the limit at which the cooling influence of irrigated living turf is no longer measurable (Figure 47). Land surface temperature data collected along each transect provided the strongest example of how temperatures vary with distance from irrigated natural living turf. UTCI provided the second strongest signal of the cooling influence of irrigated living turf. Air temperature demonstrated the weakest signal of how living turf provides a cooling influence on its surroundings.

While air temperature is influenced by the surface temperature, it is also highly susceptible to the thermal influence of all nearby surfaces as wind mixes the influences of surface heat from various surfaces before they reach the 1.2 m air temperature sensor. UTCI, of which air temperature is 1 of 4 components, also intakes the radiative globe temperature which is influenced by the amount of heat being reflected and emitted from the surface. Surface temperature is directly attributed to the thermal properties of the surface type and hence has the strongest signal.

The range of influence is calculated as the point at which the temperature trend reverses direction. For instance, if a sensor at the 1 m mark shows a warming trend of +0.5 °C and the 2 m mark shows a cooling trend of -0.5 °C, then the point of transition is calculated as 1.5 m. This method is designed to quantify the range of influence of well-resolved relationships, such as present in the surface temperature data, but becomes less precise with weaker signals, especially with high variation between adjacent stations.

Across all landscape surface types, the cooling influence of irrigated living turf on surface temperatures was measured 2.92 m away from the living turf edge, on average. The influence on UTCI was measured up to 1.46 m, on average. The influence of air temperature ended at 0.74 m away from the edge of the living turf surface, on average.

Of the five surfaces examined, natural turf had the broadest cooling range over bitumen, extending its surface temperature cooling influence to 3.64 m. The range of influence was slightly shorter for synthetic turf and non-irrigated living turf, both influencing surface temperatures beyond 3 m. The range of influence of natural turf over bare ground and playing surfaces was smaller but still measured over 2 m.

Thermal comfort was influenced at a range of 1 to 2 m across all target surfaces with its greatest reach over non-irrigated natural turf. The influence of irrigated natural turf on air temperature was greatest for synthetic turf, providing a cooling influence 1.6 m away. Air temperatures over other surfaces lost influence within 1 m from the natural turf.

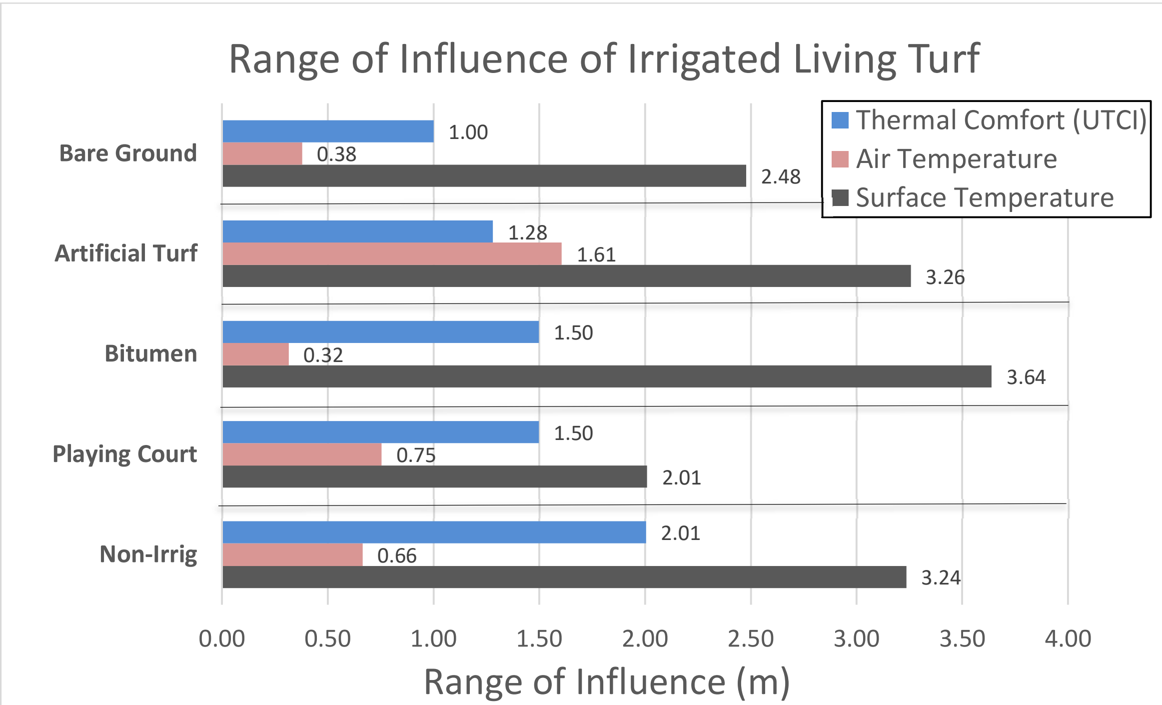


Figure 47. Range of influence of irrigated living turf over varying surface types.

3.4.2 Connection between surface and air temperature

The air temperature and UTCI transects reveal consistent results over both natural turf and target surfaces, which suggests that the connection between surface and air temperatures is operating at scales not adequately measured by the 8 m transect at 1.2 m height, influencing air temperatures most strongly at lower levels and contributing to warming differences over broader areas.

The near-ground air temperature sensors deployed at 10 cm height over the synthetic turf in Victoria and NSW show a much stronger relationship between surface and air temperature, with 10 cm high sensors measuring 5.9 and 4.5 °C warmer, respectively, than the 1.2 m high sensors, even in moderate wind conditions. This suggests the connection between surface to air is strongest near-ground level and dissipates rapidly with altitude especially in windy conditions.

The varying wind conditions also provide further insight into this connection. First, the strong inverse correlation (coefficient: -0.8) between wind speed and maximum temperatures in SA suggest that wind mixing plays a strong role in distributing heat throughout the air column. In the synthetic turf transect (Figure 26) average air temperatures were 1.4 °C warmer than over natural turf at the 4 m mark. When the winds reduced, the maximum temperature more than doubled to 3.3 °C warmer than over the natural turf. This suggests that, in the absence of wind, a stronger signal is present that more closely resembles the signal observed in the near-ground sensors. In such a case, the air temperature increased directly attributable to a hot surface effects a much larger area, beyond the capture of the 8 m transect.

To further explore this complicated relationship between surface and air temperatures, a windless vertical air temperature transect experiment was conducted over three surfaces: irrigated living turf, non-irrigated living turf, and bitumen. Over each surface a Kestrel 5500 sensor was deployed at 10 cm above ground level with a second Kestrel X3 deployed at 1.2 m above ground level. The ground level sensor was protected from the wind using a 50 cm x 50 cm x 50 cm box which effectively removed the influence of wind while minimally impeding surface warming. The 1.2 m sensor remained exposed to general wind conditions to simulate the conditions present in the horizontal field transects.

On average, across all three surface types ground level (10 cm) air temperatures were warmer than the 1.2 m temperatures (Figure 48). Over irrigated living turf, the near ground air temperatures measured 3.30 °C warmer than air temperatures at 1.2 m. Over non-irrigated living turf, the near ground air temperatures measured 7.06 °C warmer than air temperatures at 1.2 m. Over bitumen, the near ground temperatures increased to 16.67 °C warmer than air temperatures at 1.2 m. This suggests that surface temperatures have a substantial influence on air temperatures, but that this warming is quickly mixed into the broader air column. As the 8 m transects were unable to resolve differences in air temperature at 1.2 m height, this implies that the surface temperature of an individual point of land effects an area of at least 4 m in all directions, and likely further. This also suggests that the choice of surface coverings does have an effect on the aggregate air temperatures over a parcel of land, and that those influences were captured in the land surface temperature assessment, but that those air temperature impacts were not resolved in the individual transects comparisons.

These results are obtained under semi-controlled conditions (i.e. windless). Similar ground level measures taken over synthetic grass under field conditions (i.e. moderate to strong winds) showed more moderate warming of 4.5 – 5.9 °C, further confirming the connection between surface temperature and air temperature, as well as the important mixing role of wind.

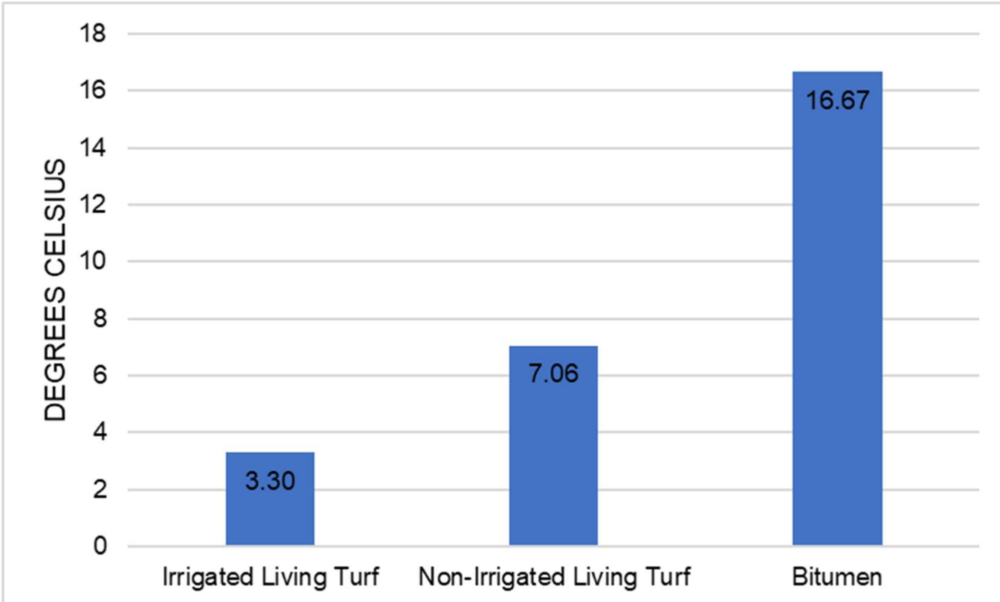


Figure 48. Ground level air temperature warming compared to 1.2m level over varying surfaces.

3.4.3 Limitations

Air temperatures closely followed BOM time of collection, meaning that at the 1.2 m level, air temperatures are the product of a much broader area, presenting the generalised temperatures of the aggregated surface temperatures. Whereas surface temperatures measure much more localised differences. Future research needs to be conducted at ground level to establish the direct connection between surface and air temperature. Because of this, surface temperature is the best metric by which to make local planning decisions as it provides the resolution necessary to understand the differences attributed to land use decisions.

The influence of wind on these results is supported by the data but not conclusive due to the limited number of data points. Further repeat investigations in controlled settings, exploring different wind speeds and wind direction, would help resolve the relationship between surface and air temperature, but given the focus on field-based data, our experimental design has provided substantial empirical insight and guidance into this question.

4 Thermal comfort and energy use

4.1 Introduction

Building on the field measurements of ground surface and air temperatures outlined in Sections 2 and 3, thermal simulations of outdoor conditions have been undertaken to better understand the consequences of temperatures on thermal comfort and building air conditioning energy use. These simulations were validated against the field measurements and then used to explore thermal comfort in both specific conditions and over the course of a year.

Simulations have also been used to explore the consequences of a regional air temperature increase due to the urban heat island effect, which is the consequence of breezes mixing all localised warm air pockets across a region and raising the overall air temperature. Even the modest 1.8 °C rise in temperatures due to urban heat island effect can significantly increase air-conditioning bills for homeowners and renters.

4.1.1 Comfort factors and calculation limitations

As outlined in Section 3, thermal comfort is affected by many factors. These factors, which are used for both indoor and outdoor thermal comfort calculations, include:

- Environmental factors:
  - Air temperature
  - Mean radiant temperature, which is calculated from
    - Surrounding surface temperatures, including areas of the sky without sun
    - Any direct sunlight
  - Air velocity (wind)
  - Relative humidity
  - Direct solar radiation (exposure to direct sunlight)
- Personal factors:
  - Metabolic rate (activity level)
  - Clothing insulation

An important consideration in the assessment of thermal comfort, especially in outdoor conditions, is that standard tools for simulating thermal comfort do not account for many aspects of real world comfort perception.

Thermal comfort calculation methodologies report comfort for a single point in space, typically located 1.2 m above ground level, which represents the middle of an adult human body. In a homogenous environment, like an indoor office far away from a window, this single-point reporting adequately represents an overall sensation of thermal comfort. But in environments with a mix of conditions close together, as experienced when standing in cool air over a hot ground surface, this single-point reporting will not capture the different sensations felt across a body.

There are many significant factors affecting human thermal comfort that are beyond the ability of standard comfort tools to measure reliably; several are relevant to this study and will distort the predicted thermal comfort results for sun-warmed surfaces like artificial turf by under-reporting the number of hours of discomfort. The missing comfort factors relevant to this study are:

- Thermal asymmetry (simultaneous exposure to both cool and warm conditions), which could result from sun-warmed ground surface disproportionately heating a person’s feel and legs only;
- Conducted heat through direct body contact with a warm surface, like bare feet on sun-warmed artificial turf, that can cause localized discomfort;
- Localised personal shading from hats, parasols, trees, and other elements that can cool a person’s head or other major body areas and redirect perception of comfort toward ground surface temperatures; and
- Momentary increases in comfort from allesthesia, or thermal delight, that result from sudden changes to the thermal environment from gusts of breeze, the sun moving in and out of clouds, or sudden changes in air temperature.

It is well documented that thermal asymmetry resulting from this kind of proximity to different surface temperatures will increase the perception of thermal discomfort. Because this study has not taken into account the possible effects of thermal asymmetry or discomfort at points close to ground level, nor the other comfort factors noted above, the results may under-represent the number of hours of thermal stress or thermal discomfort.

4.1.2 Outdoor thermal comfort

The industry standard metric for assessing outdoor thermal comfort is the Universal Thermal Climate Index (UTCI). Accordingly, this study uses UTCI as its metric for the assessment of outdoor thermal comfort related to ground materials.

UTCI is defined as the air temperature of the reference condition causing the same model response as actual conditions. It can be described as a “feels like” temperature. For example, when the air temperature is 28°C, the relative humidity is 50%, and the sun is shining on you, the UTCI is 34°C, which is the equivalent, or “feels like”, air temperature. This calculated temperature is then matched to an associated thermal stress category. In this case, 34°C would be perceived as a “strong heat stress.”

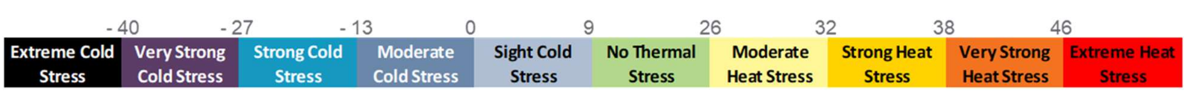


Figure 49. UTCI “feels like” temperatures and associated thermal stress categories.

UTCI is calculated using a formula that accounts for all of the environmental and personal factors listed above. It is important to note that personal factors are locked by the calculation method and cannot be changed.

4.1.3 Indoor thermal comfort

Predicted Mean Vote (PMV) is the industry standard metric for assessing indoor thermal comfort. PMV uses the same environmental factors, but uses a different algorithm than UTCI that is suited towards mechanically conditioned indoor environments. For the indoor comfort studies in this analysis, PMV will be used.

It is important to note that PMV takes into account all of the personal and environmental factors used for UTCI and other comfort metrics, except direct solar radiation. Because of this omission, it is not appropriate to use PMV for thermal comfort studies outdoors or in areas indoors that are exposed to substantial direct sun.

Comfort is achieved in office environments with a PMV of +/- 0.5, which equates to about 10% of people dissatisfied.

-3	-2	-1	0	1	2	3
Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot

Figure 50. PMV ratings and associated comfort categories

Another indoor comfort metric is the adaptive comfort metric. This metric is intended for use in naturally ventilated spaces only, where no mechanical cooling system is installed. This metric is not used for this analysis.

4.2 Outdoor thermal comfort

4.2.1 Method

Simulation tools

Industry standard tools for assessing the thermal performance and energy use of buildings include Energy Plus, IES-VE, Design Builder, eQuest, and others. These tools are capable of simulating indoor environments to a high level of detail. As a part of this process, the temperatures of outdoor surfaces are also calculated as a function of the physical properties of the surface material. While these tools do calculate outdoor surface temperature, they are not capable of assessing the resulting outdoor air temperature or outdoor mean radiant temperature over those surfaces. Thus these tools cannot directly predict localised outdoor thermal comfort, nor the broader effect of surface temperatures on heat island impacts to our urban environment.

In developing a methodology to simulate outdoor comfort, the team screened thermal modelling tools for their ability to both produce outdoor surface temperatures, and to calculate the cooling effects of evapo-transpiration of plants, which is critical to modelling the surface temperature of living turf. Only EnergyPlus has this capability, so it was selected to provide outdoor surface temperature simulations as well as indoor air-conditioning energy use for the analysis.

Simulation time scale

In this study, thermal comfort has been calculated over two time scales. First, comfort was calculated for a single moment (also called a moment-in-time calculation), using as inputs the set of environmental conditions measured at that moment. This approach allowed the calibration of simulation results with field measurements, which report a single set of data that represent conditions at one moment. These moment-in-time studies allow us to understand the relative contributions to thermal comfort of the different comfort parameters (e.g. surface temperatures, air temperatures).

Comfort can also be calculated across a series of moments to investigate how changing environmental conditions change comfort over time. For this study, comfort across all hours of a year were calculated to understand how many more hours of comfort or discomfort would result from changing ground surface materials. Annual comfort studies use environmental data measured once each hour across a full year at weather stations near the study locations. These annual studies allow us to understand the number of hours per year that people will experience different comfort levels.

Calculating outdoor thermal comfort

To calculate UTCI, most of the inputs were taken from a weather data file captured at weather stations near the field study locations. These data files include hourly measurements of solar radiation, wind velocity and humidity. The weather files used are a TMYx format, which stands for Typical Meteorological Year. In this annual weather file format, actual months of measured weather data are selected from the selected X number of immediate past years to represent "typical" conditions. For these simulations, TMY7 files were used, which have been assembled from the years 2012-2018. The weather files used data from the following weather stations near the field test sites:

- Sydney Olympic Park
- Adelaide International Airport
- Melbourne International Airport

The air temperatures for the simulation-based UTCI calculations were also obtained from these weather files. Air temperature data from a weather file accurately characterises surrounding local air temperatures during windy days, regardless of ground surface, when higher air movement mixes air across a region and dilutes the effects of localised warming due to higher ground surface temperatures.

This method of calculating comfort using the air temperature from the weather file rather than a localised air temperature simulation is supported by the measured data (reviewed in Section 3). These data show that despite local surface temperature increases, local air temperature stays relatively constant, and similar to the coincident air temperature from the weather files. This is the result of warmer ground-warmed air being mixed into the general air mass overhead by either prevailing breezes, or on still days through convection-driven mixing.

The only variable that cannot be obtained from the weather file is the mean radiant temperature (MRT). This is approximated from the outdoor surface temperature obtained from the EnergyPlus simulation. This surface temperature is then entered into a spreadsheet calculation to approximate MRT.

The personal variables are set by the UTCI calculation algorithm and cannot be changed. Below is a summary of the input sources for the UTCI calculations undertaken for this study:

- Environmental factors:
  - Air temperature (weather file)
  - Mean radiant temperature (EnergyPlus simulation & spreadsheet calculation)
  - Air velocity (weather file)
  - Humidity (weather file)
  - Direct solar radiation (weather file)

- Personal factors:
  - Metabolic rate (embedded in UTCI calculation assumptions)
  - Clothing insulation (embedded in UTCI calculation assumptions)

<u>Outdoor thermal comfort model setup</u>
To calculate the Mean Radiant Temperature inputs for the UTCI metric, the simulation tools need to accurately represent ground surface temperatures. Standard thermal energy modelling tools do not model the surface cooling effects of evapo-transpiration that keep irrigated turf cool. However, the EnergyPlus tool does have the ability to model living turf on a roof, including its evapotranspiration cooling effects. So, to calculate mean radiant temperatures for this study, the outside "roof" surface temperature of an unconditioned underground "zone" was used to represent living turf on the ground. Since the unconditioned zone is submerged into the ground plane, it takes on similar thermal profiles as the ground. The report will refer to these simulated roof surfaces as ground surfaces throughout for clarity.

The exterior surface temperature of the ground was calculated using the five different ground cover types:

- synthetic turf;
- bitumen / Asphalt;
- bare ground;
- playing Court / Concrete; and
- living turf.

The properties of these ground cover types, which come from material definition files included in EnergyPlus, are described in Table 3.

:

Table 3. Inert ground surface properties for simulation.

	Conductivity (W/m-k)	Density (kg/m3)	Specific Heat (J/kg-K)	Thermal Absorptance	Solar Absorptance
Synthetic Turf	0.42	975	650	0.9	0.92
Bitumen / Asphalt	0.75	1700	920	0.9	0.82
Bare ground	1.0	1250	1480	0.9	0.75
Playing Court / Concrete	1.51	2000	960	0.9	0.65

The additional properties needed to simulate evapotranspiration of living turf ground cover type, which also come from material definition files included with EnergyPlus, are described in Table 4.

Table 4. Living turf ground surface properties for simulation.

	Input
Height of plants	0.0635
Leaf Area index	1.0
Leave Reflectivity	0.22
Leaf Emissivity	0.95
Conductivity of Soil	0.35 W/m-K
Density of Dry Soil	1100 kg/m3
Specific Heat of Dry Soil	1200 J/kg-K
Thermal Absoprtance	0.9
Solar Absorptance	0.7

4.2.2 Results

Moment-in-Time Outdoor Thermal Comfort Results

To better understand the relative importance of individual environmental factors affecting thermal comfort, and to illustrate the overwhelming influence of exposure to direct sunlight on outdoor thermal comfort, a sequence of moment-in-time UTCI calculations were analysed for Sydney, Melbourne, and Adelaide. The individual variables tested are ground surface temperature (representing irrigated turf and synthetic turf), air temperature (ambient and ground-warmed), and solar exposure (shade and full sun). The variables all represent relative extremes, and the combinations are arranged from most to least comfortable (coolest to hottest).

Together, the variables represent a full range of outdoor comfort conditions: from a relatively cool condition in shade and standing on irrigated turf, to a relatively hot condition over synthetic turf and exposed to full sun. The specific combinations tested were:

1. BASELINE: Full shade, Irrigated turf, Ambient air temperature (no local warming);
2. Full shade, Synthetic turf, Ambient air temperature;
3. Full shade, Irrigated turf, Higher air temperature (plus 3.3 °C);
4. Full shade, Synthetic turf, Higher air temperature (plus 5.9 °C);
5. Full Sun, Irrigated turf, Higher air temperature; and
6. Full Sun, Synthetic turf, Higher air temperature.

The conditions for these moment-in-time simulations are the same as for the measured outdoor conditions for the field studies that were undertaken into the effects of sheltered environments on local air temperature over different ground surface materials. The "higher air temperature" cases illustrate a condition when either the air is still or adjacent sheltering structures like garden walls or dense vegetation prevent prevailing breezes from diluting local ground-warmed air.

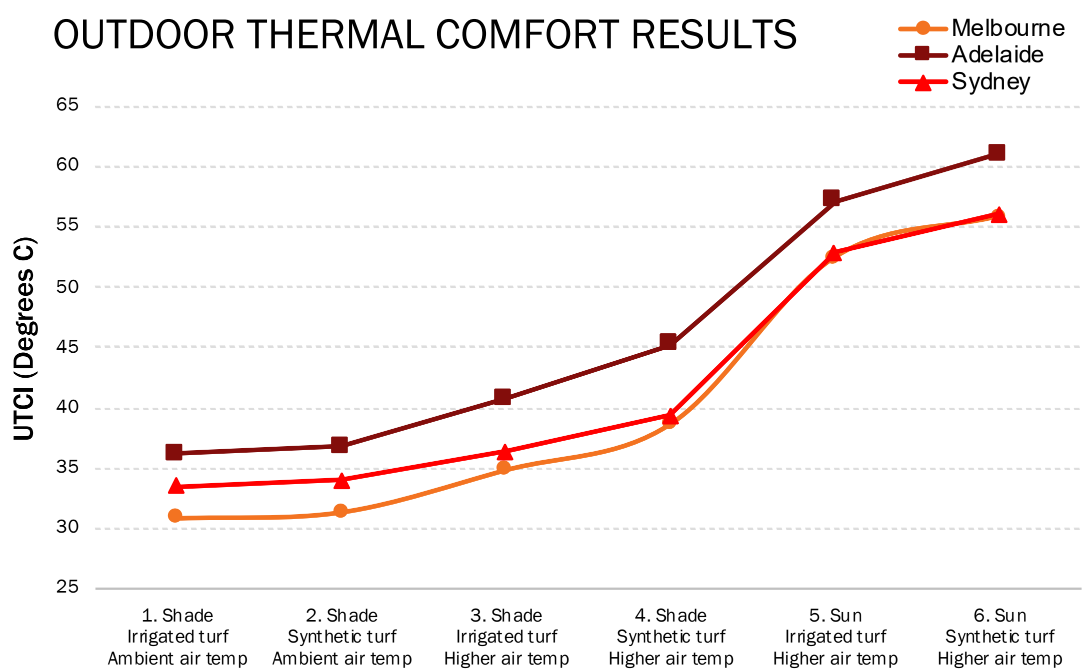


Figure 51. Outdoor comfort relative to changing exposure.

The outdoor thermal comfort simulation analysis presents several important results. First, the results show that a change of ground temperature alone, even as high as the 10°C jump in surface temperature from irrigated turf to synthetic turf, has a small effect on overall perceived thermal comfort, around 1°C change in UTCI across all sites (Figure 51, see graph between "Full Shade Irrigated Turf" and Full Shade – Synthetic Turf"). This is too small a change in conditions to be perceived as a change in thermal stress. This suggests that a change in turf surface alone probably will not change a person's perception of thermal comfort.

Next, the results show that a local rise in air temperature due to warm ground does materially change perceived comfort, in the order of 6-8°C in UTCI across all sites. (Figure

51, see graph between “Full Shade Irrigated Turf” and Full Shade – Synthetic Turf, protected”). This difference is large enough to be perceived as a small increase in thermal stress. This suggests that for areas where synthetic turf has been installed and is protected from prevailing breezes, or on very still days, synthetic turf can warm air around a person on that turf to the point that the person will feel slightly less comfortable.

Finally, the results illustrate that the addition of direct solar exposure to these environments has a substantially higher impact on thermal comfort, in the order of 25°C increase in UTCI. (Figure 51, see graph between “Full Shade Irrigated Turf” and Full Sun – Synthetic Turf, protected”). This represents a significant increase in thermal stress. And relative to the other factors explored, the magnitude of this increase far outweighs the effects of other warming from either the ground temperature increase or local air temperature increase. This means that a person’s perception of comfort will be dominated by whether or not the person is in shade, either from trees, structures, or even personal shade from a hat.

Based on the scenarios assessed in Figure 51, thermal stress is increased a little (1°C) by the increased surface temperature of synthetic turf, and up to 8°C in cases where a warm surface is sheltered from any prevailing breezes. However, the number of degrees increase in UTCI, which affects whether the thermal stress is perceptible, depends on the circumstances. These results also illustrate that for the scenarios analysed, synthetic turf has consistently higher heat stress predicted than the irrigated turf option. How these higher ground temperatures affect comfort outdoors, comfort indoors, and energy used for heating and cooling adjacent buildings is further explored in the following sections.

The simulation results (Figure 51) are similar to the field measured results, showing that thermal stress over synthetic turf is consistently higher than over natural turf as a result of the higher surface temperature of synthetic turf. The simulation results also align with the field studies in showing that over land areas generally open to prevailing breezes, which dilute any ground-warmed air, ground temperature induced thermal stress is very small, on the order of 1°C, and is almost imperceptible as a change in thermal comfort. The simulations also show that in sheltered areas that do not experience air movement, ground temperature can drive up local air temperature and increase thermal stress by as much as 8°C (Figure 20), which will be perceived as a decrease in thermal comfort.

<u>Sheltered area scenario relevance</u>

The results of the Moment-in-Time Outdoor Thermal Comfort analysis and the measured data presented in Section 3.3 both have shown that an increase in air temperature over warmer ground is greater, and thus able to be perceived as a change in thermal comfort, when there are very low wind speeds. Since a measurable increase in thermal stress will only be achieved on warm days with very low airspeeds, the number of hours per year where this might occur was calculated for Sydney (Paramatta), Adelaide, and Melbourne using the measured weather data noted in Section 4.2.1. For the cities below, the number of hours when ambient air temperature is > 28°C and unobstructed wind speed is < 2 m/s is as follows:

- Sydney: 11 hrs per year
- Adelaide: 5 hrs per year

- Melbourne: 1 hr per year

The limited number of hours with coincident still air and warm temperatures suggests that localised shelter from prevailing breezes will be the predominant factor in determining whether a location experiences air warmed by increased ground temperature. This will be especially important in courtyard homes or other closed in environments such as school yards with large buildings surrounding closed in areas of open space.

Another implication of this analysis is that the main way open sites will experience a decrease in thermal comfort is from the general effects of regional air warming resulting from a myriad of warm surfaces that lead to the creation of urban heat islands. To assess the broader impact of hot ground surfaces like synthetic turf, this study assessed the effect that general urban heat island warming has on indoor thermal comfort (Section 4.3) and indoor heating and cooling energy use (Section 4.4).

Annual outdoor thermal comfort results

In addition to the moment-in-time assessments of thermal comfort resulting from ground surface material changes, the effects of these ground surface materials on outdoor thermal stress over the course of a year was simulated for Sydney, Melbourne, and Adelaide (Figures Figure 52 - Figure 54). These simulations calculate thermal stress for all 8,760 hours of a year using measured hourly weather data from the TMYx weather files described in Section 4.2.1.

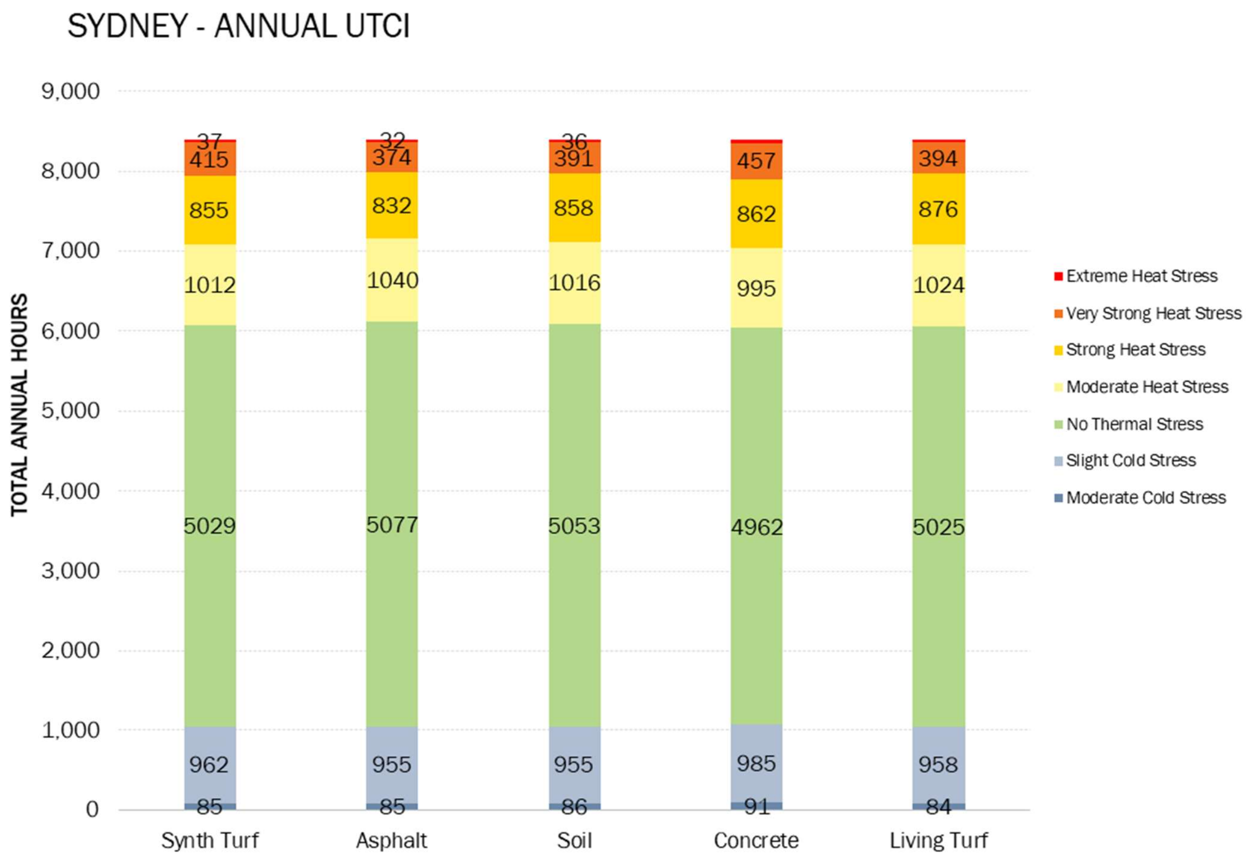


Figure 52. Sydney Annual UTCI, grouped by thermal stress.

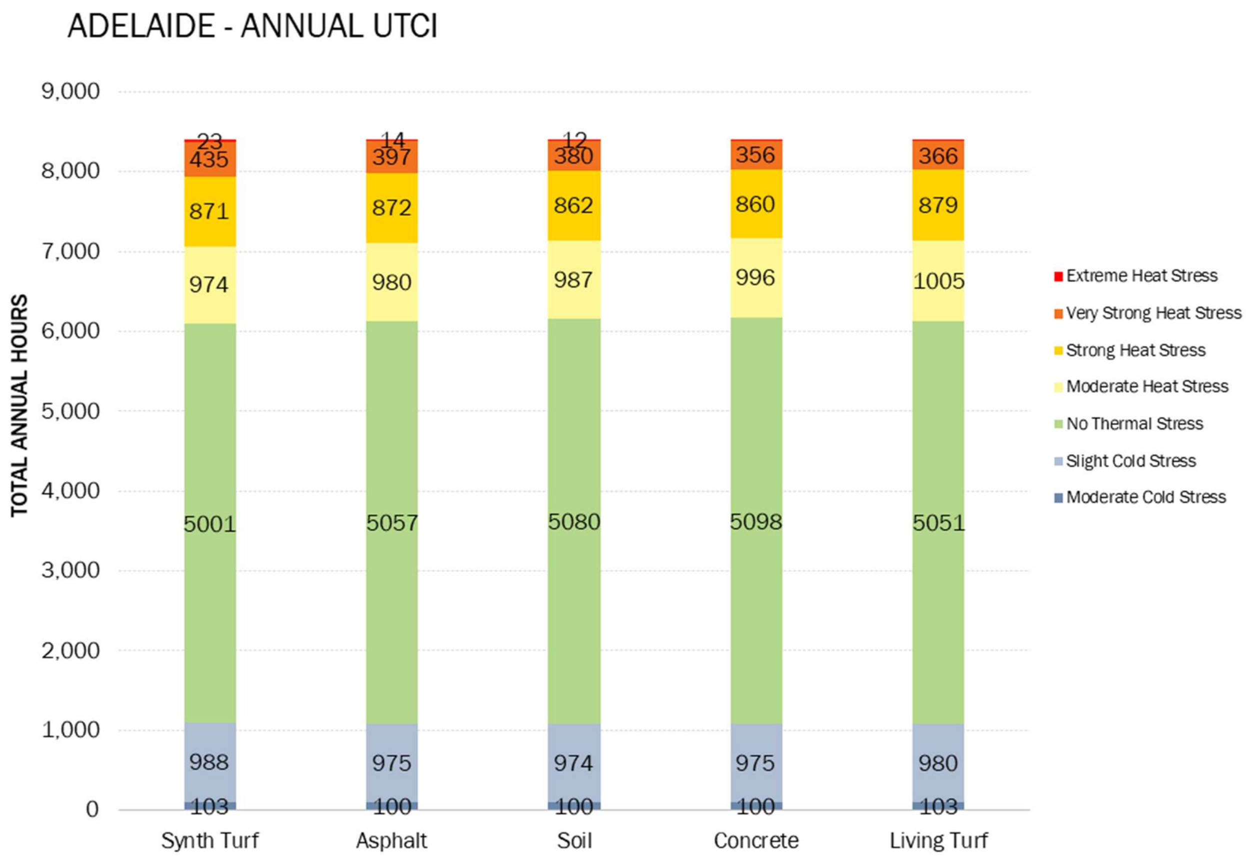


Figure 53. Adelaide Annual UTCI, grouped by thermal stress.

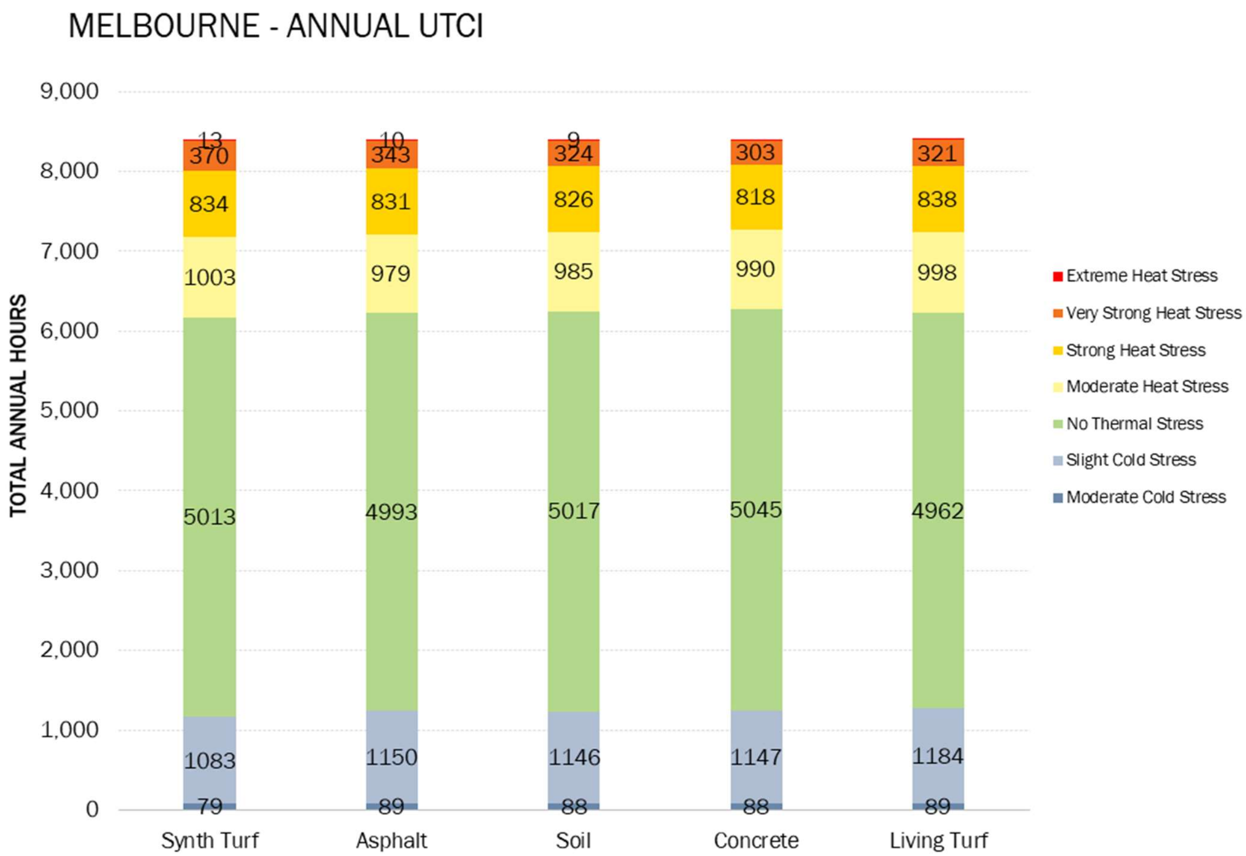


Figure 54. Melbourne Annual UTCI, grouped by thermal stress.

The simulated annual surface temperature results agree with the measured data from Section 2, which show that all of the surfaces have significant increases in temperature relative to the temperature of living turf. The EnergyPlus simulations showed playing courts with the highest surface temperature, followed by bitumen, artificial turf, and bare ground. Living turf was at least 10°C cooler than all of these surfaces during the peak day condition.

However, just as in the moment-in-time comfort simulations, the impact of elevated surface temperatures due to synthetic turf and other hard ground materials on UTCI over the course of the year is small. This results in simulated UTCI that is very similar across different ground cover types. These simulated results are again supported by the measured results (Section 3), which also show a similar UTCI across the different ground cover types.

As was observed for the moment in time comfort calculations (Figure 51), a person's perception of outdoor comfort over the course of a year is dominated by exposure to direct sunlight. To explain this further, the impact of direct solar radiation can be expressed analytically as a "solar adjusted mean radiation temperature," a process by which the MRT (which includes the effect of ground surface temperature) is increased to account for the added impact of direct solar. The direct solar adjustment is typically many times larger than the ambient air temperatures or even the MRT. For example, on a January day where the dry bulb temperature is 30°C and the MRT is 38°C, the solar-adjusted MRT is 106°C. This direct solar effect on thermal comfort dwarfs any other contributing environmental factor, including ground surface temperature or air temperature.

Even without the direct solar factor, prevailing breezes dilute localised air warming therefore diminishing the annual effects of ground material on thermal comfort perception. Because of these factors, the simulated results show a minimal difference in annual hours of thermal stress and resulting different thermal comfort levels across the different turf types.

4.3 Indoor thermal comfort

4.3.1 Method

If outdoor conditions change substantially, they will also affect comfort in adjacent buildings. To test the effect of increased ground temperature resulting from varying ground materials on indoor comfort, a single-story residential room with a large window was modelled and located adjacent to an outdoor area with ground that was changed between surface temperatures representing irrigated living turf and synthetic turf. This provides insights into the indoor thermal comfort impact that might be experienced in homes or buildings in schools. In both ground cases, the outdoor area is assumed to be sheltered from prevailing breezes, allowing outdoor air temperature to rise when ground conditions are warmer. Comfort conditions within the building were calculated for each outdoor ground condition.

The room modelled had wall, floor, and roof construction that complies with thermal insulation requirements of the building code current at the time of analysis (National Construction Code 2016). The construction type in the simulation has a light thermal mass, so the surface temperatures were the same as the air temperatures, typical of lightweight framed construction. The operative temperature within the room (a combination of air and surface temperatures) was set to match an outdoor air temperature resulting from the ground condition. This mimics the effects of localized natural ventilation through open windows determining the indoor thermal conditions of a house.

For this calculation, the Centre for the Built Environment (at University of California Berkeley) Thermal Comfort Tool was used (http://comfort.cbe.berkeley.edu/). This tool facilitates the calculation of PMV by taking into account operative temperature (air temperature + mean radiant temperature), air speed, humidity, metabolic rate, and clothing levels of occupants.

For this calculation, the following inputs were used:

- Operative temperature – base condition: 25°C
- Operative temperature – ground warmed condition: 29°C
- Humidity: 50%
- Metabolic rate: 1.1
- Clothing level: 0.5 (typical summer indoor clothing)
- Indoor air speed: 0.2 m/s

4.3.2 Results

Under the base condition, which represents cooler irrigated turf and still air, the predicted PMV is -0.4, which is considered neutral and comfortable. Under the "ground warmed" condition, which represents synthetic turf and air warmed by the hotter ground surface, the predicted PMV is +0.92, which is considered slightly too warm.

As was the case with outdoor thermal comfort, the slight decrease in indoor thermal comfort resulting from ground-warmed air would only occur when still air conditions allow a rise in outdoor air temperature, which in turn warms the inside of the room. The still conditions could result from either lack of a breeze or from localized sheltering structures (fences, tall hedges and trees) that would block breezes. An increase in ground temperature alone would not materially change indoor temperatures due to the limited exposure inside to that warm ground plane.

4.4 Energy assessment

As outdoor conditions change, they can affect the energy used to heat and cool rooms in adjacent buildings. The effects of ground surface warming, and consequent local air warming, were investigated using thermal simulation to understand the effects of ground surface on home heating and cooling energy use and energy costs.

4.4.1 Method

The simulated and measured ground surface temperature and air temperature results indicate that under the limited conditions assessed few hours per year will see measurable outdoor air temperature increases resulting from hotter ground surface temperatures. Because of this, the full potential impact to building heating and cooling energy use from a change in ground material cannot be calculated using a normal energy modelling methodology as conventional methodology precludes potential effects of localized air warming resulting from a combination of sheltering structures like fences and hedges and changed ground surface materials like synthetic turf. Conventional energy modelling also cannot take into account regional temperature increases due to urban heat island effects as the simulation tools cannot directly calculate regional air temperature differences due to warmer or cooler surfaces.

To account for the potential warming that may occur under some circumstances due to surface material selection, the impact to heating and cooling energy was simulated by assigning an average air temperature increase of 1.85°C across every hour of the year. This is intended to represent the urban heat island effect and aligns with the average projected increase in air temperatures due to climate change by mid century. The consistent temperature increase of 1.85°C is not necessarily how urban heat island temperature profiles would be distributed either spatially or across a 24-hour daily temperature cycle, but the order of magnitude is appropriate and sufficient to represent the general change in indoor conditioning energy.

Results from this urban heat island affected weather file have been compared to results from the original, unaltered weather file. The difference in results illustrates how ground-warmed synthetic surfaces can affect building heating and cooling energy use.

To determine the energy use impact from the urban heat island effect on a residence, a simple energy model was created. This model represents a block of six residential apartments. As with the earlier indoor comfort calculations, the thermal performance of walls, windows, floors and ceilings of the model was set to comply with the code current at the time of analysis (NCC 2016). Also as before, construction type was low thermal mass, representing framed construction rather than masonry. For consistency, the same inputs for internal gains and constructions were used across all climate zones.

- Area: 74 m^2 / unit
- Window to wall ratio: 40%
- Wall R-value: 2.8
- Roof R-value: 3.2
- Window U-value: 3.5
- Window SHGC: 0.4
- Lighting: 5.0 W/m^2
- Plug loads: 5.0 W/m^2
- Occupancy: 2 people per unit
- Heating setpoint: 19°C
- Cooling setpoint: 25°C

The weather files used for the simulations are the same TMYx files used in all comfort assessments:
- Sydney Olympic Park
- Adelaide International Airport
- Melbourne International Airport

To simulate the increase in outdoor air temperature, new weather files were created that added 1.85°C to the drybulb temperature for every hour of each file. This created new temperature "shifted" environmental scenario weather files. Annual heating and cooling energy simulations were modelled using each location pair of original and shifted weather files, and the difference between resulting energy use for each weather file determined the impacts to heating and cooling energy.

For each of the three cities modelled, two conditioning energy use scenarios were modelled. The first scenario is a "cooling only" model, where the only assumed supplemental heating or cooling source is mechanical cooling (air conditioning). This represents houses that have installed central air conditioning or window air conditioners that run regularly, but do not have regular central or other heating sources. The second scenario is a "heating and cooling" model, representing houses where there is a central mechanical heating and cooling system, conventionally a reverse-cycle split system that provides year-round centrally controlled cooling and heating both.

The two scenarios were created to understand the relative impact of the additional warming on cooling, where it will detrimentally increase energy use, and heating, where it will beneficially reduce energy use.

4.4.2 Results

Cooling energy and cost results

In areas that experience urban heat islands and where residences only have cooling installed (Table 5), the consistently warmer air temperatures resulting from the urban heat island effect have the potential to raise annual cooling energy use and associated utility costs by between 48% to 72% (Table 6). Energy cost increases at exactly the same rate as energy use because there is only one source of cooling energy – electricity – in all scenarios.

Adelaide and Sydney cooling energy increases are similar, and the magnitude suggests that the additional air conditioning load from the urban heat island effect mostly increases loads on days when air-conditioning is already needed. The much larger increase in Melbourne cooling energy use suggests that the urban heat island effect creates many more days when air conditioning would turn on, thereby adding both load and increasing number of hours of air-conditioning run time.

	Normal Weather – Cooling Energy (kWh/m2)	Shifted Weather – Cooling Energy (kWh/m2)	% Increase in Cooling Energy
Sydney	18	30	51%
Adelaide	13	20	48%
Melbourne	6	10	72%

Table 5. Annual cooling-only energy increase resulting from urban heat islands.

	Normal Weather – Cooling Utility Cost ($/m2)	Shifted Weather – Cooling Utility Cost ($/m2)	% Increase in Cooling Utility Cost
Sydney	$5.0	$7.6	51%
Adelaide	$5.1	$7.5	48%
Melbourne	$1.9	$3.3	72%

Table 6. Annual cooling-only energy cost increase resulting from urban heat islands.

Heating and cooling energy and cost results

While the 1.85°C urban heat island effect increases summer air conditioning loads, it also provides a beneficial reduction in winter space heating needs, with Sydney seeing a net heating and cooling energy use increase while Adelaide and Melbourne see net energy use decreases (Table 7). Whether a location experiences a net energy increase or decrease depends on the relative balance of heating and cooling needs for a specific climate.

Melbourne, which is heating dominated and has relatively few cooling days, sees a substantial benefit for reduced heating loads of 29% that far outweighs the cooling energy increase. Adelaide, with more balanced heating and cooling needs, sees a smaller net energy reduction benefit of 10%. Sydney, with a temperate climate that rarely needs heating, sees a net energy use increase of 14% because most house conditioning energy needs are for cooling.

	Normal Weather – Total Energy (kWh/m2)	Shifted Weather – Total Energy (kWh/m2)	% Increase in Total Energy
Sydney	27	31	14%
Adelaide	29	27	-10%
Melbourne	48	34	-29%

Table 7. Annual total energy increase, with gas heating, from urban heat islands.

Net energy use and cost benefit also depends on the relative energy efficiency of the heating and cooling systems. In the gas-fired furnace heating system modelled (Table 7), the efficiency is around 80%, meaning 80% of the primary energy source – gas, in the case of these heating energy simulations – is turned into useful heat. By comparison, cooling systems typically have an energy efficiency of 300% or higher, meaning the heat pump in the refrigeration system can deliver three times the thermal energy output relative to the electricity energy input. In houses with low-efficiency heating, the beneficial winter time warming reduces heating energy use substantially more than it increases cooling energy needs due to the substantially different heating and cooling system efficiencies.

If these houses were to have reverse-cycle heating, with an efficiency of closer to 200%, the relative benefit of urban heat island warming would be greatly diminished because there is less heating source energy to offset (Table 8). In this scenario, only Melbourne sees a net benefit from urban heat island warming because of its heating dominated climate. Adelaide and Sydney both experience a net energy increase resulting from their proportionally longer cooling seasons.

	Normal Weather – Total Energy (kWh/m2)	Shifted Weather – Total Energy (kWh/m2)	% Increase in Total Energy
Sydney	21	29	36%
Adelaide	18	22	18%
Melbourne	19	18	-9%

Table 8. Annual total energy increase, with reverse-cycle electric heating, from urban heat islands.

Heating and cooling costs resulting from urban heat island warming differ from the energy cost or savings when gas is the heating source. This discrepancy from total energy benefit or cost results from the relative cost difference between gas and electricity, with gas costing less than electricity per unit of thermal energy delivered. In this gas-fired heating scenario, only Melbourne sees a net decrease in total utility costs (Table 9). Both Sydney and Adelaide experiences a cost increase resulting from urban heat island effect.

	Normal Weather – Cooling Utility Cost ($/m2)	Shifted Weather – Cooling Utility Cost ($/m2)	% Increase in Cooling Utility Cost
Sydney	$6.1	$7.7	27%
Adelaide	$7.2	$7.8	7%
Melbourne	$5.0	$3.7	-25%

Table 9. Annual total energy cost increase, with gas heating, from urban heat islands.

If the heating system is an electric heat pump with a 2.5 Coefficient of Performance (COP, or measure of energy efficiency), energy and cost impacts are the same because the thermal source energy is electricity for both heating and cooling. In this scenario, Melbourne still sees a net cost benefit from urban heat island warming, but only 9% (Table 10). Adelaide and Sydney see even larger energy cost resulting from urban heat island warming.

	Normal Weather – Cooling Utility Cost ($/m2)	Shifted Weather – Cooling Utility Cost ($/m2)	% Increase in Cooling Utility Cost
Sydney	$5.8	$7.9	36%
Adelaide	$7.1	$8.4	18%
Melbourne	$6.4	$5.8	-9%

Table 10. Annual total energy cost increase, with reverse-cycle electric heating, from urban heat islands.

Other urban heat island cost benefit considerations

Urban heat islands also incur costs that are outside the scope of this study but which should be factored into any rigorous analysis of urban heat island impacts. The costs to the built environment include:

- increased construction costs for more insulation against higher temperatures;
- possible decreased equipment life resulting from a greater number of operational hours;
- decreased service life of heat-sensitive building materials like sealants, caulks, and other flexible connections; and
- increased costs for vegetation replacement due to overheating.

The health costs resulting from urban heat islands include:

- increased hospitalisation resulting from heat stress; and
- increased hospitalisation resulting from dehydration.

There is a wide body of literature on the costs of urban heat islands that can be consulted for more information on this topic.

5 Consequences of climate change

The urban heat island effect is the product of average temperatures across the built environment being warmer than what would have been present in the natural environment. As such, widespread warming of all surfaces is unlikely to change the relative temperature difference between cities and their surroundings, and therefore unlikely to change the number and size of urban heat islands (though general warming will likely increase heat island magnitude). What will change, however, is the frequency and severity of extreme heat events, the impacts of which will be experienced to a much greater extent within urban heat islands.

Ultimately, land use choices will determine the characteristics of future urban heat islands with more cooling surfaces decreasing the heat island effect and more warming surfaces increasing the effect. While the thermal response of many surfaces will be similar under a changing climate, some surfaces may have different thermal responses under different conditions. For example, changes in precipitation will alter the thermal response of some landscapes such as non-irrigated grass whereby in wetter conditions these landscapes provide a cooling influence but in drier conditions they contribute to heating. Other climate changes, such as increased solar radiation may prioritise different heat mitigation strategies such as increasing shaded areas, as the thermal comfort benefits of avoiding increased solar radiation may outweigh the cooling benefits of changing landscape types.

Climate change will drive broad changes in the climate of capital cities, specifically increasing temperatures, increasing solar radiation, and decreasing precipitation, all of which affect land surface temperatures, air temperatures, and thermal comfort. Land use decisions will determine the degree to which people living in cities and larger regional towns are exposed to future extreme heat events, and how they experience them.

5.1 Land surface changes

The land surface temperature assessment (Section 2) provides a detailed breakdown of the thermal characteristics of typical land surfaces, with constructed surfaces such as bitumen and synthetic turf creating a warming effect of over 5 °C on average and natural surfaces such as irrigated and non-irrigated natural turf providing a cooling effect of over 3 °C on average. Based on these findings, the future composition of our landscapes then in turn determines the future impacts of climate change with areas that have increased the proportion of cooler surfaces (irrigated living turf, light surfaces, trees) faring better than areas that have seen increases in warmer surfaces (synthetic grass, dark rooves, bitumen). As the climate is projected to warm by at least 1.5 °C by mid-century in the major capital cities (Figure 55), the selection of cooling, natural surfaces can more than offset that warming at local scales. While these choices are generally made at individual and community levels, they are influenced by national, state, and council policies.

5.2 Thermal performance changes

The relative thermal performance of most landscapes remains unchanged when faced with warming conditions (i.e. bitumen is warmer than irrigated grass on a 10 °C day and a 40°C day). One surface that does vary is non-irrigated grass which can be a major warming or major cooling surface depending on the level of precipitation. Non-irrigated grass can appear as annual grasses that dieback during hot and dry summers that occur in much of southern Australia, or species of perennial grass like couch or kikuyu that can brown off if conditions remain persistently dry.

During drier periods and in drier climates the surface temperature of non-irrigated grass is close to bitumen and provides a strong warming effect. Understanding future climate conditions will help determine the suitability for certain options in certain locations, such as if non-irrigated grass planted will provide continued cooling into the future or if it is likely to become an unintended hot spot under future conditions.

Water bodies are another land use feature that may have different thermal responses in the future. Generally, all water bodies provide a cooling effect, but shallow water bodies are closer to ambient temperatures at night. Under prolonged heat events in the future, shallow water bodies may warm enough that they begin acting as warming surfaces during the night. This is important given that night time warming is a driver of increased mortality during extreme heat events (Laaidi et al., 2011).

5.3 Climate change in Australia

The CSIRO 2018 State of the Climate Report demonstrates that Australia's climate has warmed by more than 1.0 °C over the last 100 years and that the rate of that increase is accelerating (State of the Climate, 2018) (Figure 55). The Climate Futures Tool, developed as part of the Climate Change in Australia (CCIA) initiative by CSIRO and the BoM, shows warming under the Representative Concentration Pathway (RCP) 8.5 (CCIA Futures, 2015). Air temperature increases in individual major Australian cities is expected to range between 1.7 and 2°C by mid-century and that range is expected to expand to 2.9 to 3.7°C by the end of the century with Brisbane and Sydney experiencing the most severe warming (CCIA Cities, 2015). Land surface temperatures are also projected to increase by 1.5 – 1.8 °C by mid-century (CCIA Futures, 2015).

In addition to warming temperatures, precipitation is also expected to continue changing. Some areas of southwest Australia have seen a 20% decrease in seasonal rainfall over the last 40 years (State of the Climate, 2018), and Perth may see a further 10% decrease by 2050 (CCIA Futures, 2015) (Figure 56). The other major cities may experience drying of closer to 3 to 8% over this period.

Separate to air temperature, other factors affecting thermal comfort are also expected to change. For example, solar radiation is projected to increase by 3.1% in Melbourne by 2090, whereas Brisbane and Perth are expected to see a 1% or less increase. The different suite of climate changes facing each city suggests that a tailored cooling strategy is necessary to effectively adapt to changing local conditions (

Table 11).

The CCIA future climate projections are based on the ensemble climate projections used in the Intergovernmental Panel on Climate Change (IPCC) Coupled Model Intercomparison Project (CMIP) 5. The ensemble averages the outputs of 45 individual global climate models, one of which is the Australian Community Climate and Earth-System Simulator (ACCESS) (Figure 57). Results from RCP 8.5 are displayed as it has tracked most closely with observed climate data from the past decade (Whetton et al., 2012).

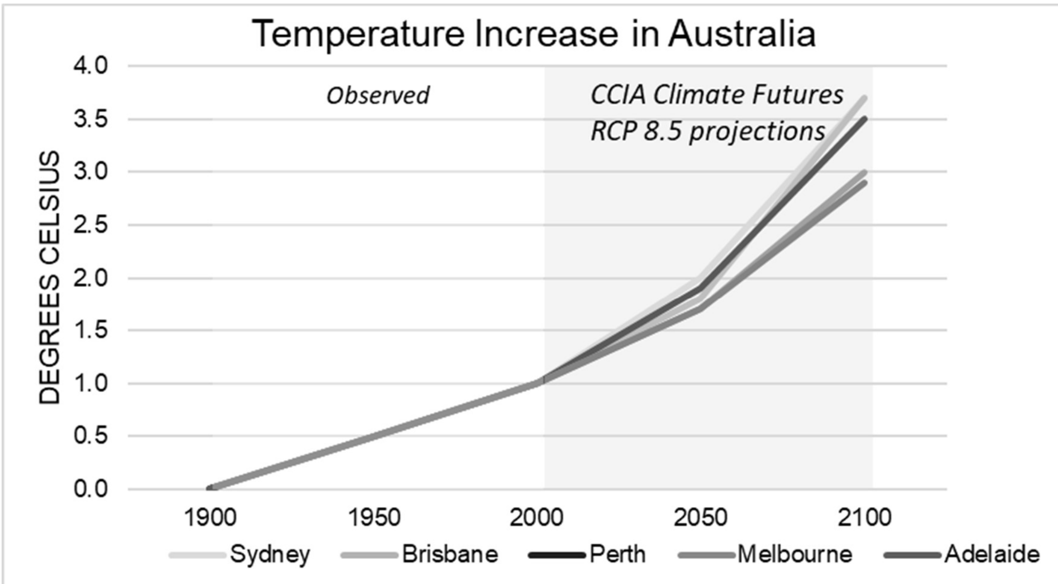


Figure 55. Observed and projected temperature changes in Australian cities.

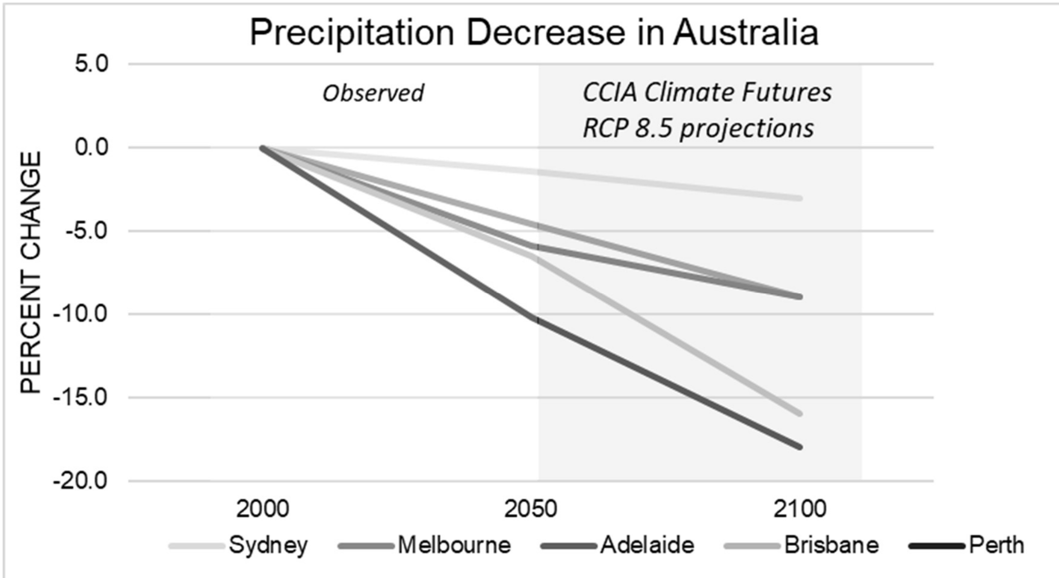


Figure 56. Observed and projected precipitation changes in Australian cities.

City	Temperature Change (2090, RCP 8.5)	Precipitation Change (2090, RCP 8.5)	Solar Radiation Change (2090, RCP 8.5)
Adelaide	2.9 °C	-9 %	1.5 %
Brisbane	3.7 °C	-16 %	0.8 %
Melbourne	3.0 °C	-9 %	3.1 %
Perth	3.5 °C	-18 %	1.0 %
Sydney	3.7 °C	-3 %	1.3 %

Table 11. Individual climate change challenges for key Australian cities.

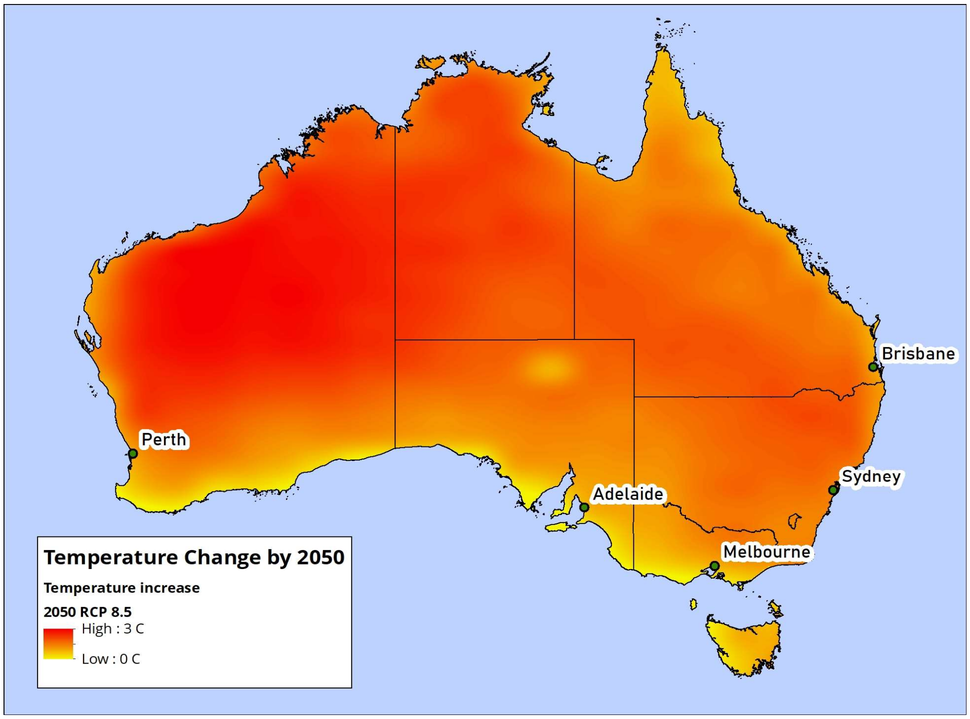


Figure 57. Temperature change between 1990 and 2050 under RCP 8.5 according to the ACCESS model.

5.4 Implications for thermal comfort and energy use

Climate change is expected to change all aspects of urban heat, with surface temperatures, air temperatures, and solar radiation increasing for every major Australian city. Given the projected changes (Table 11), thermal comfort is expected to become hotter by 1.6 °C in Perth, 1.8 °C in Brisbane, 1.9 °C in Adelaide, 2.4 °C in Sydney, and 2.6 °C in Melbourne by 2090.

The five major capital cities are expected to warm by 1.85 °C by mid-century. The implications of this magnitude of temperature increase on energy consumption, is described in Section 4.4.

5.5 Implications for adaptation

Urban heat islands present a challenge for all Australian cities with major cities around the world expected to be spending upwards of 10% of local GDP to combat heat island effects by mid-century (Zhou et al., 2017). In addition to economic impacts, health is also affected with 1 °C warming being linked to an increase of 2-5% in mortality (Yu et al., 2012).

Given the anticipated climate changes, each major Australian capital city will need to develop specific strategies to help cope with changing conditions. In projected higher rainfall areas, such as Sydney and Brisbane, non-irrigated grass is less likely to dry-out and become a major hot spot. As such, in these areas expanding non-irrigated grass may be a suitable option for achieving mild cooling.

In areas that are expected to dry, such as Perth, Adelaide and Melbourne, non-irrigated grass presents a potential liability in that these areas are likely to become major hotspots and heat islands under climate change. Such areas should be considered for irrigation where this is feasible, such as through the use of alternative water supplies such as treated wastewater or stormwater. The need to balance the cooling benefits gained from water consumption for urban greening versus managing increasing water security issues will be a key challenge for city planners and decision makers in the future

In Melbourne, where solar radiation is projected to increase by 3%, more shading may be most effective at reducing extreme heat exposure. Furthermore, light coloured roofs and road surfaces are expected to be most effective in areas with higher degrees of solar radiation (CHPP Report, 2016) suggesting that light pavements may be most impactful in areas such as Perth and Adelaide, currently, and Melbourne in the future. In all cities, replacing hot land surfaces (bitumen, synthetic grass) with cool land surfaces (irrigated living grass, trees) will reduce land surface temperatures and provide relief for the immediate and surrounding areas.

6 Key findings

The analysis of surface and air temperatures as part of this study has provided significant insight into the impact of living turf, synthetic turf and other common land surface types of the thermal environment.

Land use thermal performance assessment

Based on analysis of landscape scale thermal data sets in three states (NSW, SA and VIC), the following key findings have been identified:

- Across the country, the surface temperature of irrigated natural turf measures 4.9 °C cooler than the baseline average surface temperature.
- In this analysis, synthetic turf – long pile was one of the hottest surfaces in the landscape measuring nearly 11 °C hotter than average. This re-enforces findings from past studies.
- There is evidence of a difference in the warming potential of synthetic turf with long versus short pile (i.e. the artificial grass blades), with the former having a greater average surface temperature. In contrast, bitumen which was included as a control, consistently fell between synthetic turf – long pile and synthetic turf – short pile.
- On average, non-irrigated natural turf provides a more moderate (1.3 °C) but highly variable cooling influence, ranging from 4.4 °C cooling in Victoria, to a 1.7 °C warming in SA. The thermal performance of non-irrigated living turf depends heavily on the seasonal precipitation during the year of data collection.
- The analysis of the thermal performance of the five landscape coverings reinforces that natural materials provide a cooling influence compared with built materials that provide a warming influence.

Surface-to-air relationship assessment

Field data was collected along transects across six surface types (irrigated living turf, non-irrigated living turf, synthetic turf, bitumen, playing courts and bare ground) during the 2018-19 summer period for air and surface temperature in NSW, SA and VIC. The following key findings have been identified:

- When compared with irrigated living turf, natural materials (bare ground and non-irrigated living turf) averaged 10 °C warming over the target surface (between the 1 m and 4 m marks), whereas synthetic materials (playing court, bitumen, and synthetic turf) averaged 23 °C of warming.
- At all times during the three hot days of data collection, average surface temperatures over irrigated living turf remained between 34 and 42 °C. Temperatures over the target surfaces ranged from 42 to 70°C, with synthetic turf being the hottest measuring between 25 and 33 °C hotter than irrigated living turf between the 1 and 4 m marks. Peak temperatures over 70°C for synthetic turf align with observations of the same material recorded in studies by Jim (2017).

- The analysis of air temperature data shows a strong negative correlation between maximum air temperatures and wind speed. This means that increased wind speeds diminish the maximum air temperatures recorded over a given surface type, in many cases masking the impact of the much higher surface temperatures of constructed or synthetic materials.

- The impact of wind mixing on air temperature at 1.2 m above the surface was shown by collection of data closer to the ground, where mixing is less pronounced. For example, the near-ground air temperature sensors deployed at 10 cm height over the synthetic turf in Victoria and NSW showed a much stronger relationship between surface and air temperature, with 10 cm high sensors measuring 5.9 and 4.5 °C warmer, respectively, than the 1.2 m high sensors, even in moderate wind conditions.

- A key metric explored in the study was the Range of Influence (RoI) which is the limit at which the cooling influence of irrigated living turf is no longer measurable. Land surface temperature data collected along each transect provided the strongest example of how temperatures vary with distance from irrigated natural living turf. UTCI provided the second strongest signal of the cooling influence of irrigated living turf. Air temperature demonstrated the weakest signal of how living turf provides a cooling influence on its surroundings.

- All of these data are within several degrees of the BOM average at the time of collection, suggesting air temperatures are the product of a much larger area, much of which may lay beyond the range of the 8 m transect. Additional investigations into the scale of variation is needed. Furthermore, wind speeds of over 1m/s seem to be a critical threshold for the transference of surface temperatures into air temperatures with calmer winds allowing those patterns to be revealed, while stronger winds mix the air sufficiently to obscure any pattern.

- Future research needs to be conducted at ground level to establish the direct connection between surface and air temperature. Because of this, surface temperature is the best metric by which to make local planning decisions as it provides the resolution necessary to understand the differences attributed to land use decisions.

While the aim of this study is not to understand the underlying mechanisms behind the additional heat stored in synthetic turf, this has been explored to aid understanding of the results. There appears to be no specific peer reviewed literature on this issue, however, based on an understanding of structure of synthetic turf, it is likely that the increased temperature is due to a combination of materials including the pile or plastic filaments used as the grass leaves, the rubber crumb which is used in some synthetic turf to provide flexibility and ease the impact when the surface is being used for sport, and the synthetic mat.

Simulated thermal comfort and energy use

Simulated thermal comfort was assessed because of its potential ability to model the different impacts of living versus synthetic turf on air temperature and hence thermal comfort outdoors and indoors. This information can then be used to estimate energy demand for cooling to improve indoor thermal comfort. The EnergyPlus tool was used because of its ability to both produce outdoor surface temperatures, and to calculate the cooling effects of evapotranspiration of plants.

Key findings of the simulated thermal comfort analysis were that:

- The simulated surface temperature results agree with the measured data from Section 3, which shows that all of the surfaces have significant increases in temperature compared with the temperature of living turf.
- The EnergyPlus tool simulations showed playing courts with the highest surface temperature, followed by bitumen, synthetic turf, and bare ground. All of these were at least 10 °C hotter than living turf during the peak day condition.
- Based on scenarios assessed for Sydney, Melbourne and Adelaide, outdoor thermal stress is increased a little (1°C) by the increased surface temperature of synthetic turf, and up to 8°C in cases where a warm surface is sheltered from any prevailing breezes. The results illustrate that for the scenarios analysed, synthetic turf has consistently higher heat stress predicted than irrigated turf.
- The analysis sought to identify the number of hours when ambient air temperature was > 28°C and unobstructed wind speed was < 2 m/s. The results showed that there are a limited number of hours with coincident still air and warm temperatures, which suggests that localised shelter from prevailing breezes will be the predominant factor in determining whether a location experiences air warmed by increased ground temperature.
- As was the case with outdoor thermal comfort, the slight decrease in indoor thermal comfort resulting from ground-warmed air would only occur when still air conditions allow a rise in outdoor air temperature, which in turn warms the inside of the room.

Due to the low observed impact of higher surface temperatures on air temperature and outdoor thermal comfort modelling of energy use used an estimated impact of urban heat island warming of 1.85°C. This temperature was selected to also align with projected mid-century impacts of climate change. The results of the analysis were that:

- In areas that experience urban heat islands and where residences only have cooling installed, the consistently warmer air temperatures resulting from the urban heat island effect have the potential to raise annual cooling energy use and associated utility costs by about 50% for Sydney and Adelaide and up to 72% in Melbourne.
- While the 1.85°C urban heat island effect increases summer air conditioning loads, it can also provide a beneficial reduction in winter space heating needs. The net energy use across both seasons is ultimately influenced by the type and efficiency of heating and cooling systems.

Climate change and heat island mitigation

Urban heat islands are not a consequence of climate change. They exist independently of climate change, however, the way in which people experience periods of extreme heat will be worse in heat islands. Many land surface features that influence the development of urban heat islands will be impacted by increasing heat in a linear way, meaning that climate change will not lead to a tipping point in their overall performance. However, green cover and especially living turf does have the potential to be dramatically affected. This is because irrigated living turf has a cooling effect, while non-irrigated dry grass can be one of the hottest surface types in the landscape.

A consequence of warmer and drier conditions is that (a) larger areas of open space will become dried grass, contributing even more to the development of urban heat islands, and/or (b) the need for increased irrigation to maintain healthy living turf. This highlights the need for local government, developers and residents to continue to proactively work together to ensure that suitable water sources, some of which may be alternative (e.g. recycled stormwater), continue to be available in the future.

What do the results mean for planning and development decisions?

The results suggest that in large areas of open space such as in occurs around irrigated sporting and recreation fields and parks and reserves, the cooling benefits from living turf are significant enough to outweigh the negative effects of surfaces such as synthetic turf and bitumen. In these areas the localised warming that does occur from hot surfaces, appears to be quickly mixed with cooler surrounding air, especially when there is even a light breeze. As such, the people walking or playing sport over these surfaces benefit from what might be considered as “borrowed cooling” from nearby cooler areas. It is anticipated that as the proportion of hot surfaces to cool surfaces increases, the overall warming signal will become stronger.

While not extensively tested for this study, the results suggest that in closed in settings, such as fenced in backyards, private open space surrounded by buildings, or even large enclosed facilities such as sports ovals or stadiums, the reduced air mixing due to lower breezes could mean that hot surfaces can more directly lead to warmer air temperatures. For example, this means that for a small home with a fenced in courtyard, living turf could be seen to more directly reduce air temperatures and improve thermal comfort, whereas synthetic turf could more directly lead to increased temperatures and reduced thermal comfort. The liveability of such spaces will also be more directly influenced by surface temperature. For example, in a backyard with limited space the extreme temperatures of synthetic turf could prove dangerous for walking with no shoes or for the unprotected feet of pets such as dogs.

A further consideration is the use of living versus synthetic turf in streetscapes, especially road verges. The higher surface temperature of synthetic turf placed over the soil surface in verges poses a significant potential risk to street tree survival and longevity due to the higher surface temperature translating to higher root temperatures. Further, the hotter soil surface can reduce moisture content and more rapidly dry out the root zone. Other impacts could be less desirable verge side areas for pedestrians.

Future research

This study provides clear, consistent information about the relative benefit of living turf in reducing surface temperatures compared with other surface materials such as synthetic turf. The evidence base in this regard is arguably amongst the most comprehensive of any in Australia. The implications of surface temperature for nearby air temperature and thermal comfort was less clear and relates strongly to the local context such as exposure to wind.

Areas for future research will be finalised in the final report for this project. However, interim recommendations are that the following issues should be further explored:

- The impact of higher relative surface temperatures of synthetic turf compared with living turf on the longevity and survival of street trees, given the importance of street trees for urban cooling and the costs associated with their establishment and maintenance;
- Deeper dive analysis into the impact of living versus synthetic turf in closed in backyards, such as occur in courtyard homes, on liveability for people and pets;
- Irrigation requirements to generate cooling benefits from living turf. This should also consider the role of soil health in creating healthy, living turf;
- The underlying mechanisms influencing the additional heat stored in synthetic turf;
- The impact of increased ground temperature on indoor temperatures in apartments, including upper level apartment rooms; and
- Options for including estimates of the impact of living turf versus other land surface types on surface temperature in urban heat island analysis tools such as those developed by the CRC for Water Sensitive Cities.

References

Bihrmann, K., and A.K. Ersbøll (2015) Estimating range of influence in case of missing spatial data: a simulation study on binary data. Int J Health Geogr. 2015; 14: 1. Published online 2015 Jan 6. doi: 10.1186/1476-072X-14-1.

Blazejczyk, K., Jendritzky, G., Bröde, P., Fiala, D., Havenith, G., Epstein, Y., Psikuta, A. and Kampmann, B., 2013. An introduction to the universal thermal climate index (UTCI).

CCIA Futures, 2015 – Climate Futures Tool, CSIRO and Bureau of Meteorology, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/), cited 22 April 2019

CCIA Cities, 2015 - Webb, L.B. and Hennessy, K., Climate Change in Australia: Projections for selected Australian cities, CSIRO and Bureau of Meteorology, Australia.

CHPP Report, 2016. Impact of Pavements on the Urban Heat Island, Center for Highway Pavement Preservation final report.

City of Melbourne, Open Data Platform 2012.

Jacobs, B., Mikhailovich, N. & Delaney, C., 2014. *Benchmarking Australia's Urban Tree Canopy: An i-Tree Assessment, prepared for Horticulture Australia Limited by the Institute for Sustainable Futures,* NSW: University of Technology Sydney.

Jim, C. Y., 2017. Intense summer heat fluxes in artificial turf harm people and environment. *Landscape and Urban Planning,* Volume 157, pp. 561-576.

Norton, B. A. et al., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning,* Volume 134, pp. 127-138.

Seed Consulting Services, Airborne Research Australia and EnDev Geographic, 2017. *Western Adelaide Urban Heat Mapping Project Report. Prepapred for for the Cities of West Torrens, Charles Sturt and Port Adelaide Enfield, and the Adelaide Mount Lofty Ranges Natural Resources Management Board.*

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.*

State of the Climate, 2018. The Bureau of Meteorology and CSIRO, Commonwealth of Australia, ISBN: 978-1-925315-97-4

Whetton P, Hennessy K, Clarke J, McInnes K, Kent D (2012) 'Use of Representative Climate Futures in impact and adaptation assessment.' Climatic Change 115, 433-442. 10.1007/s10584-012-0471-z.

Yu W, Mengersen K, Wang X, Ye X, Guo Y, Pan X, Tong S. (2012). Daily average temperature and mortality among the elderly: a meta-analysis and systematic review of epidemiological evidence. Int J Biometeorol. 56(4): 569-81.

Zhou, B., Rybski, D. and Kropp, J.P. (2017). The role of city size and urban form in the surface urban heat island. *Scientific reports 7*(1) p.4791.

Appendix A. Land surface temperature datasets

Land surface temperature data from the following councils were analysed through the course of this process.

City	State	Resolution	Year of Data
Parramatta	NSW	1 m	2013
Adelaide	SA	2 m	2018
Burnside	SA	2 m	2018
Campbelltown	SA	2 m	2018
Charles Sturt	SA	2 m	2017
Norwood Paynham & St. Peters	SA	2 m	2018
Port Adelaide Enfield	SA	2 m	2017
Prospect	SA	2 m	2018
Salisbury	SA	2 m	2018
Tea Tree Gully	SA	2 m	2018
Unley	SA	2 m	2018
Walkerville	SA	2 m	2018
West Torrens	SA	2 m	2017
Melbourne	VIC	1 m	2012
Port Phillip	VIC	0.5 m	2010

Appendix B - Fact Sheet

HEAT MITIGATION OF LIVING TURF

Why does heat in our cities matter?

Urban heat has a major impact on how people live in our cities, with extreme heat killing more people than any other natural hazard. It also reduces the overall health and well being of the community and makes our economy less productive.

Cities around Australia have developed heat islands as they have changed from natural to built landscapes, replacing cooler green open spaces and trees with constructed materials that retain heat. Understanding how heat islands develop and how to cool cities can be done by knowing how different land surfaces types heat up during summer. This is especially important as our cities become hotter over the coming decades in response to climate change.

About the project

Hort Innovation funded a study, delivered by Seed Consulting Services, to understand the heat reduction benefits of irrigated turf compared with other land surface types in our cities. The study combined spatial information using thermal cameras with on-ground field studies in Sydney, Melbourne and Adelaide.

The project assessed the land surface temperature of irrigated turf compared with non-irrigated turf, synthetic turf and bitumen. The results across all three capital cities showed that irrigated turf had a much lower average surface temperature compared with non-irrigated turf, synthetic turf and bitumen (refer to infographic over the page). The project also found that living turf is cooler than city-wide average surface temperatures, whereas synthetic turf and bitumen are warmer than average.

How can the results of this study be used?

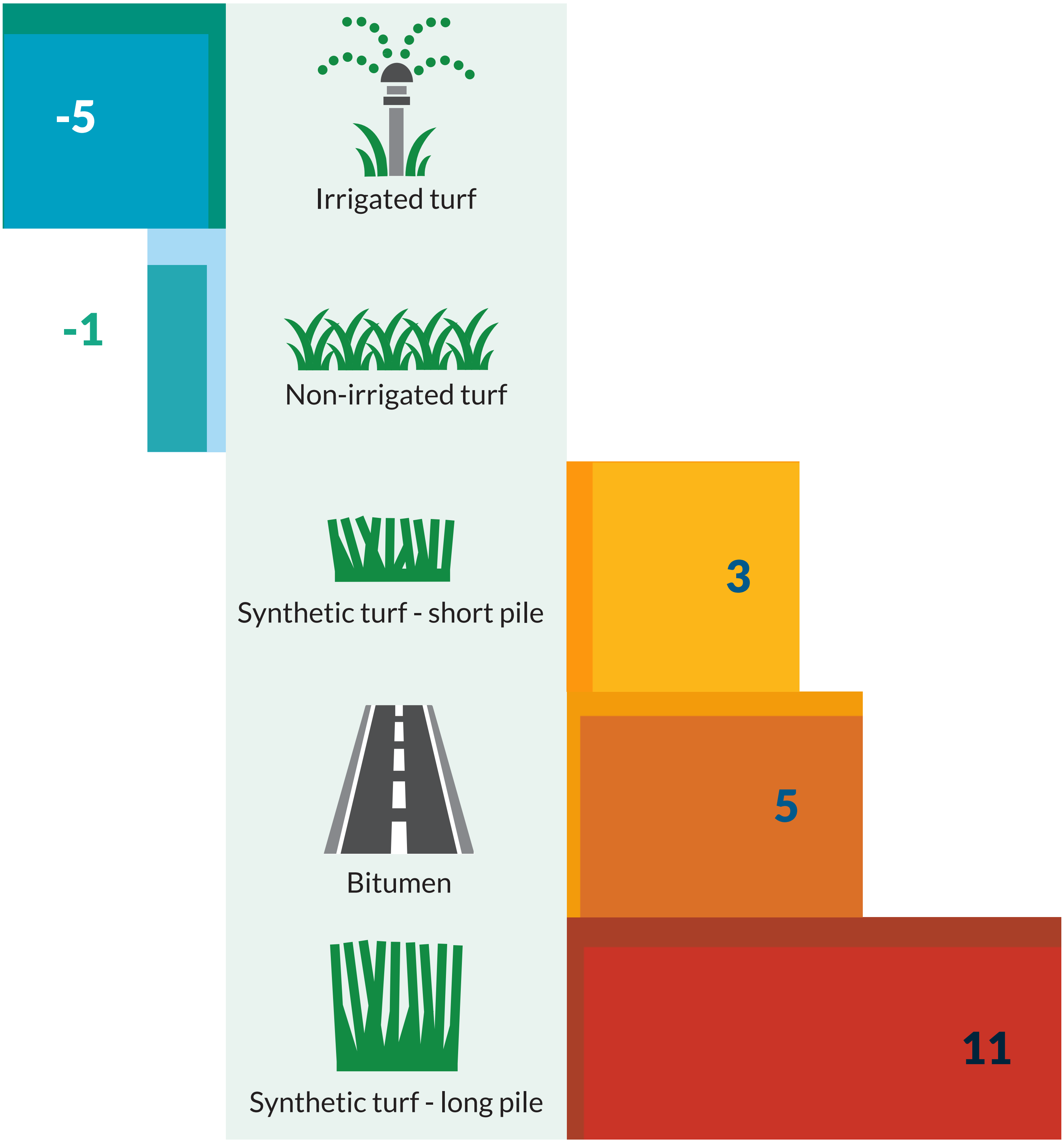
The results of this study show that planning and construction decisions made today are affecting how cool or hot our cities will be in the future. A choice of irrigated living turf can help to cool areas of open space, whereas bitumen and synthetic turf can create hot surfaces, which contribute to heat islands at a street and park through to city scale.

This information has been developed as part of the Hort Innovation Turf Fund project Conveying the benefits of living turf - mitigation of the urban heat island effect (TU18000), which has been funded using the turf R&D levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Hort Innovation
Strategic levy investment

TURF FUND

Warming and cooling in degrees celsius of surface temperature



Full details of the research will be made available at www.horticulture.com.au/turf

Appendix C - Example of PowerPoint slide deck used for national seminar series

seed consulting services

EnDev Geographic

atelier ten

Growing cool cities – The role of irrigated green cover

Dr Mark Siebentritt
Seed Consulting Services
28 August 2019

ADELAIDE – BRISBANE MELBOURNE – PERTH - SYDNEY - BRISBANE

1

Hort Innovation
Strategic levy investment

TURF FUND

Conveying the benefits of living turf - Mitigation of the urban heat island effect

TU18000

2

Hort Innovation
Strategic levy investment

TURF FUND

- Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australia's horticulture industry
- One of the nation's 15 Rural Research and Development Corporations tasked with investing horticulture levies and Australian Government contributions into initiatives to help the industry be as productive and profitable as possible.

3

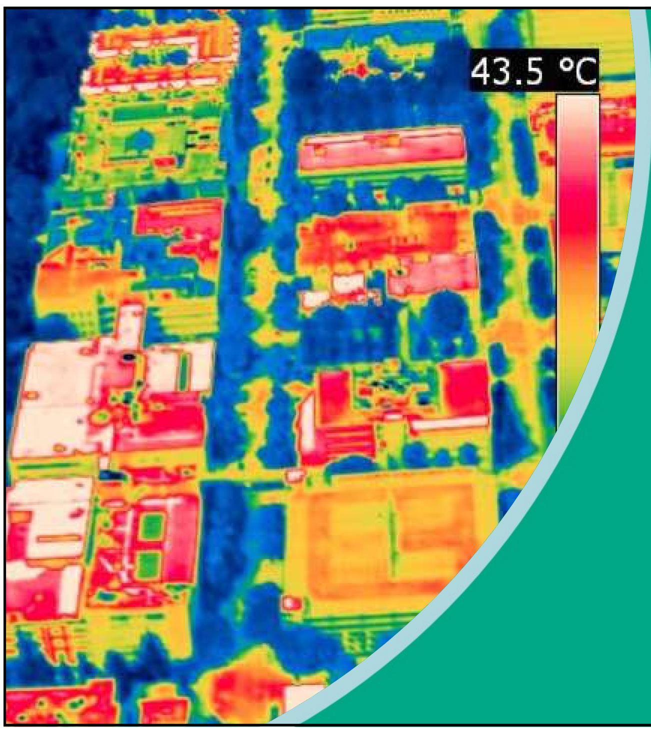
What are the cooling benefits of irrigated green space, especially living turf, and how should this inform future decisions about how we cool, and grow, our cities?

4

Overview

1. Why does urban heat (and cooling) matter?
2. What causes urban heat islands and how can irrigation help?
3. What is the impact of different land surface types on heating and cooling?
4. How could surface materials impact energy demand?
5. What does it mean for climate change?
6. Wrap up

5



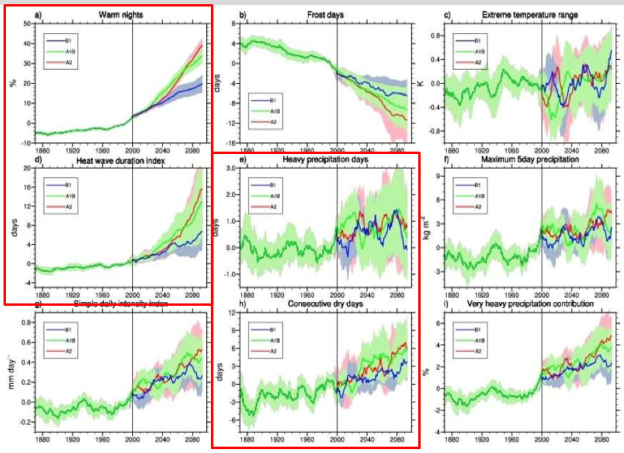
Why does urban heat (and cooling) matter?

6

Australian Climate Stressors

MONASH University

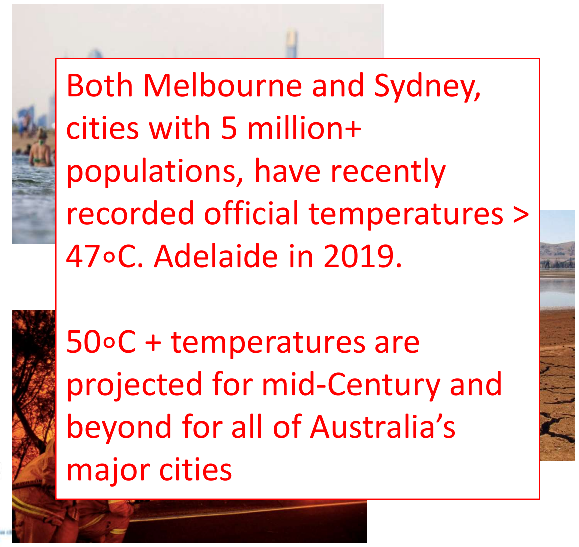
Slide courtesy of Prof Nigel Tapper



Time Series of Extremes for the Australian Region 1870-2099

Alexander and Arblaster, 2009

MONASH University



Both Melbourne and Sydney, cities with 5 million+ populations, have recently recorded official temperatures > 47∘C. Adelaide in 2019.

50∘C + temperatures are projected for mid-Century and beyond for all of Australia's major cities

7

Why are heat islands important?

- Extreme heat kills more people than any other natural hazard.
  - 1 °C warming being linked to an increase of 2-5% in mortality
- Extreme heat impacts the community, environment, and economy
  - Unchecked, cities will be ***spending up to 10%*** of GDP to mitigate UHIs
  - The total economic cost to the community due to hot weather is estimated to be approximately $1.8 billion in present value terms. Approximately one-third of these impacts are due to heatwaves. Of the total heat impact, the Urban Heat Island effect contributes approximately $300 million in present value terms. (AECOM 2012)
- The accumulation of heat in urban areas can result in urban heat islands, which experience temperatures higher than the surrounding landscape
- Under climate change, the impact of higher temperatures will become more evident in these areas
- Decisions today matter

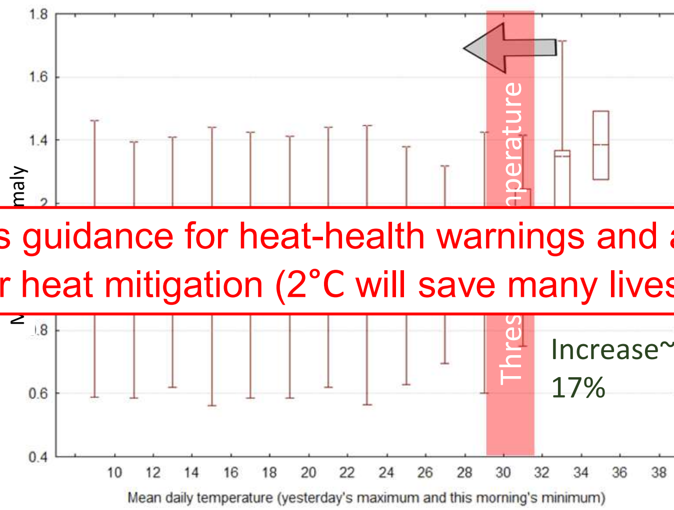
8

Improved public heat warnings and emergency services preparedness to save lives

MONASH University

Melbourne – Heat Threshold for Excess Deaths in > 64 year olds

MDT of 30°C = (40°C+20°C)/2



Provides guidance for heat-health warnings and a target for heat mitigation (2°C will save many lives)

Nicholls, Skinner, Loughnan and Tapper, 2008

9

"While land surface temperature and air temperature are different, addressing high surface temperatures in cities is an appropriate target"

Norton, B. A. et al., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning, Volume 134, pp. 127-138.

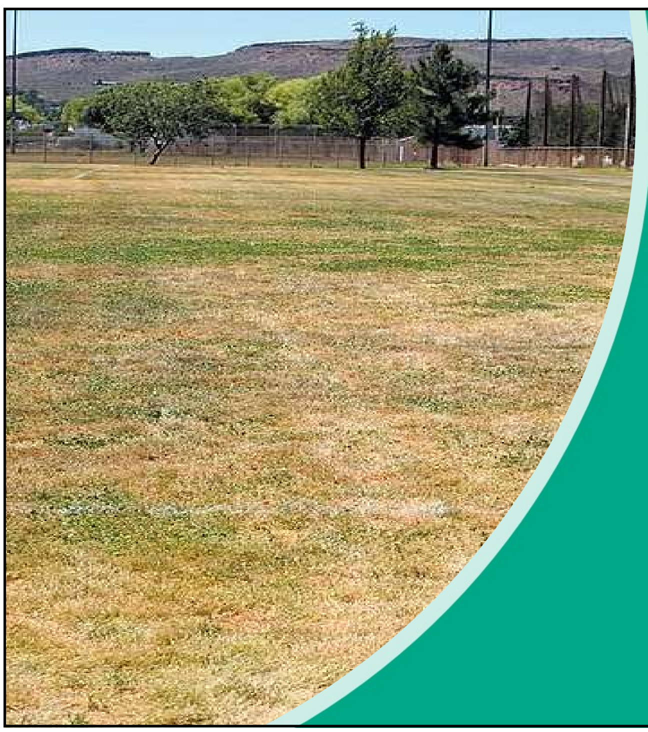
10





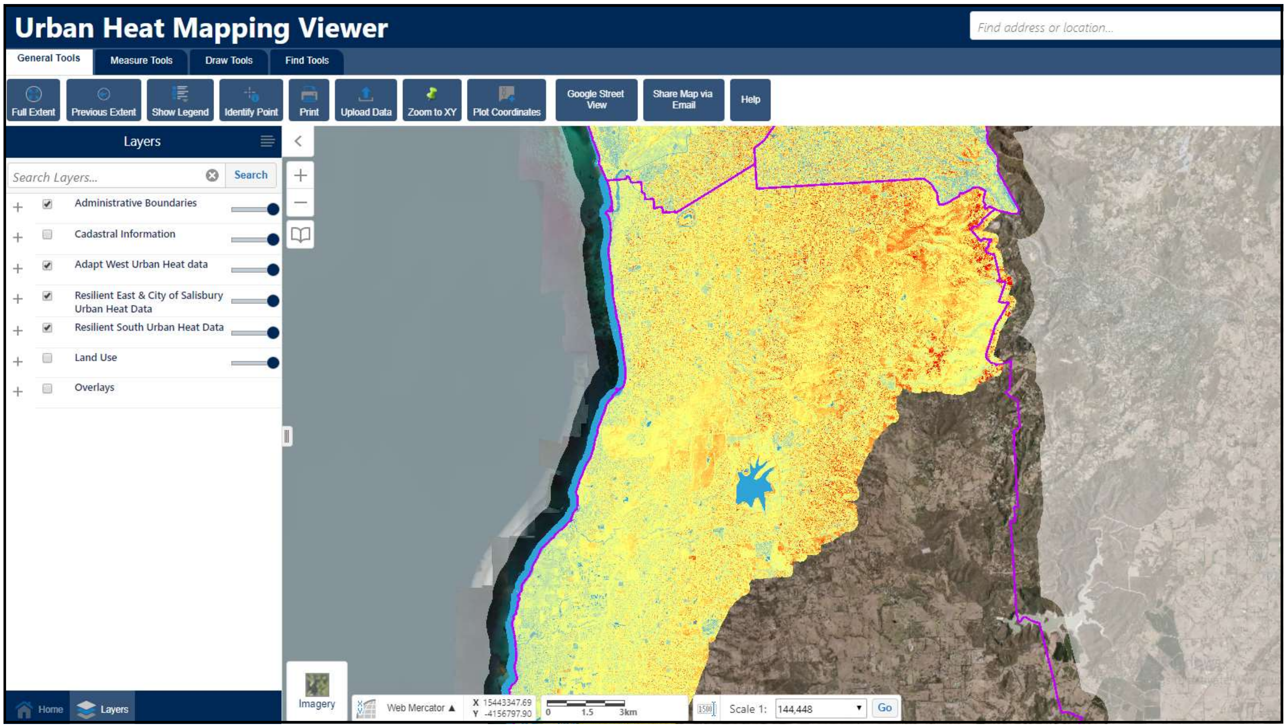
How do we measure heat?

11

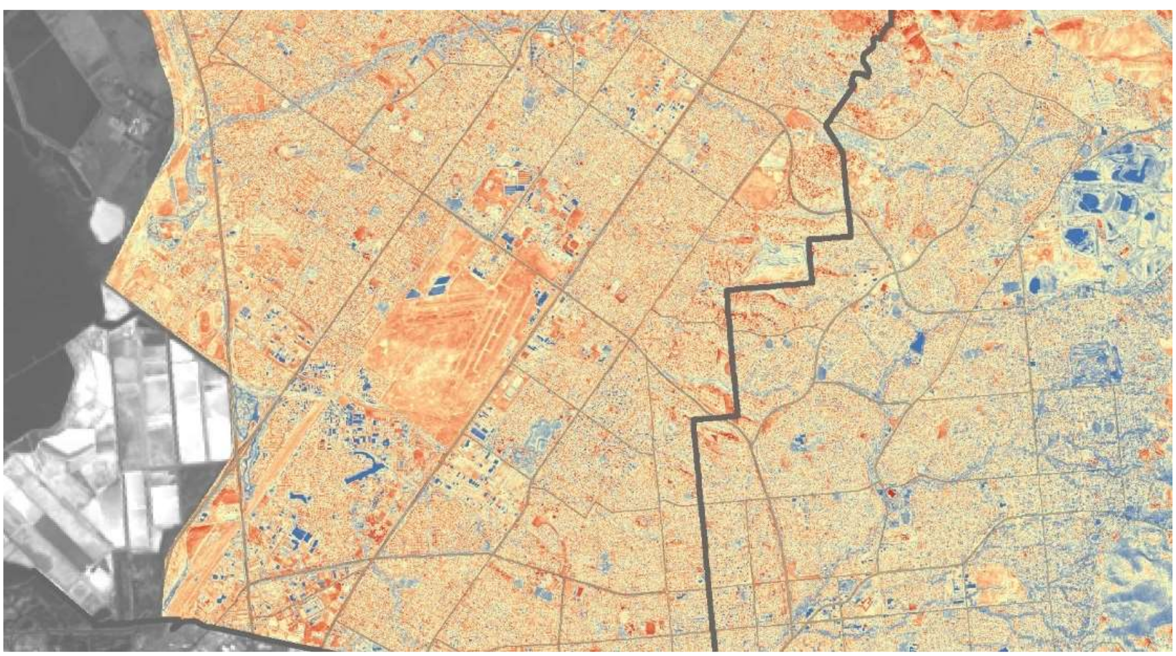


What causes urban heat islands and hot spots and how can irrigation help?

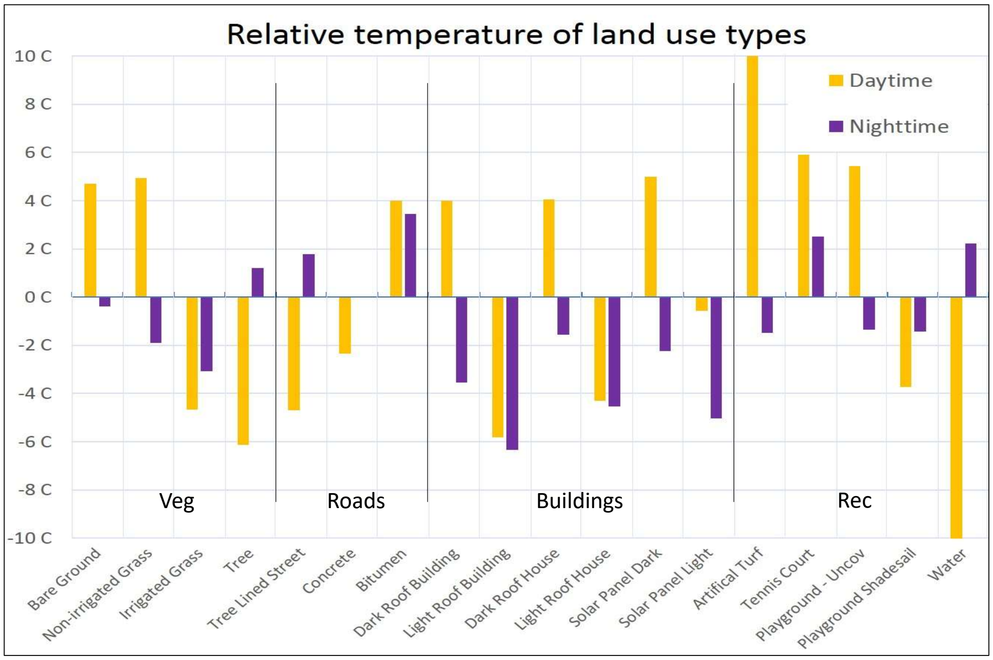
12


Urban Heat Mapping Viewer
Find address or location...
General Tools
Measure Tools
Draw Tools
Find Tools
Full Extent
Previous Extent
Show Legend
Identify Point
Print
Upload Data
Zoom to XY
Plot Coordinates
Google Street View
Share Map via Email
Help
Layers
Search Layers...
Search
Administrative Boundaries
Cadastral Information
Adapt West Urban Heat data
Resilient East & City of Salisbury Urban Heat Data
Resilient South Urban Heat Data
Land Use
Overlays
Home
Layers
Imagery
Web Mercator
X 15443347.69
Y -4156797.90
0 1.5 3km
Scale 1:
144,448
Go

13



14



Source: 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.

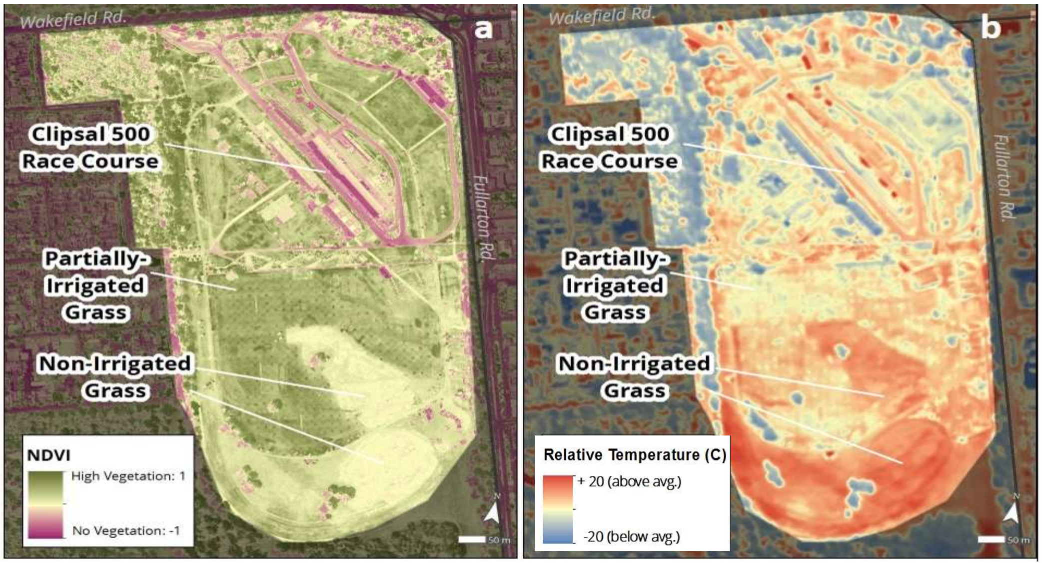
15

Source: Seed Consulting Services, Airborne Research Australia and EnDev Geographic, 2017. Western Adelaide Urban Heat Mapping Project Report. Prepared for the Cities of West Torrens, Charles Sturt and Port Adelaide Enfield, and the Adelaide Mount Lofty Ranges Natural Resources Management Board.

16

Irrigated grass versus non-irrigated grass (Adelaide Parklands)

Victoria Park

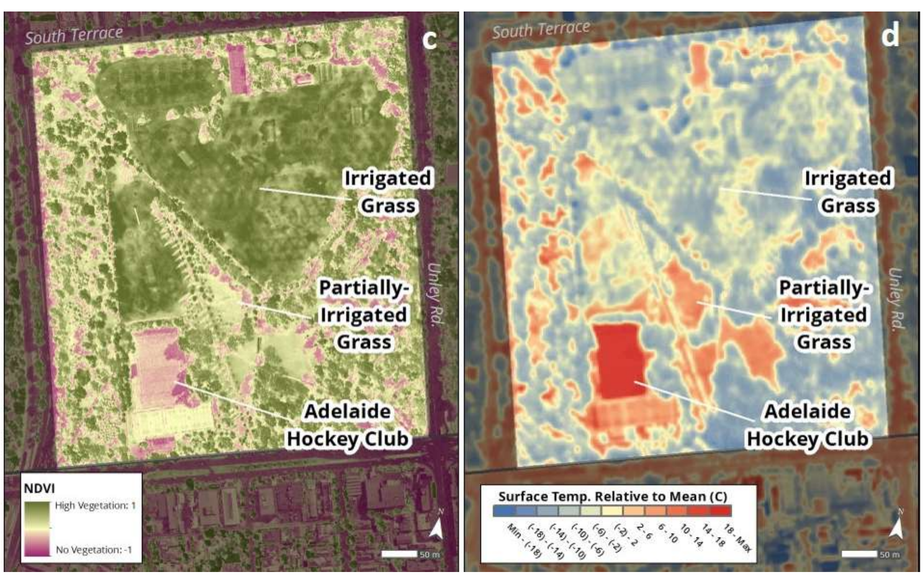


Source: Seed Consulting Services, EnDev Geographic and Monash University, 2018. Collaborative Heat Mapping for Eastern and Northern Adelaide Report. Prepared for the City of Unley on behalf of the Eastern Region Alliance of Councils and the City of Salisbury.

17

Irrigated grass versus non-irrigated grass (Adelaide Parklands)

Pulteney Fields



Source: 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.

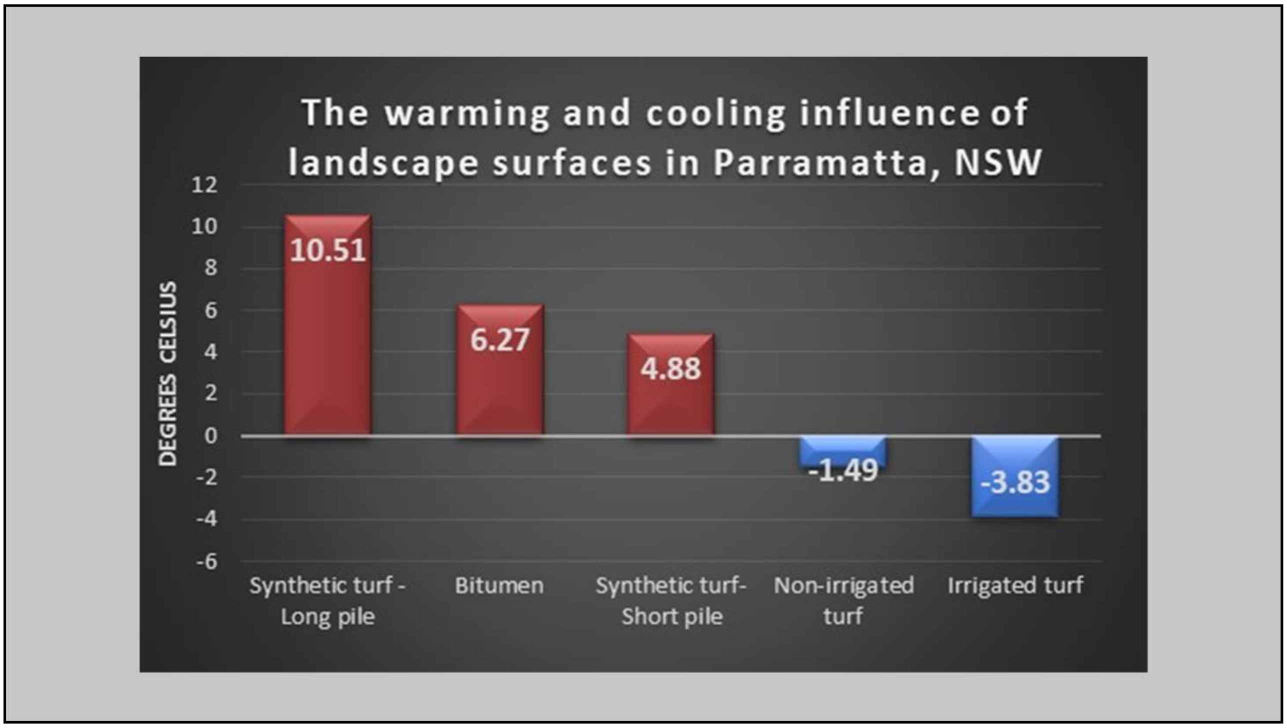
18

What is the impact of different land surface types on temperature?

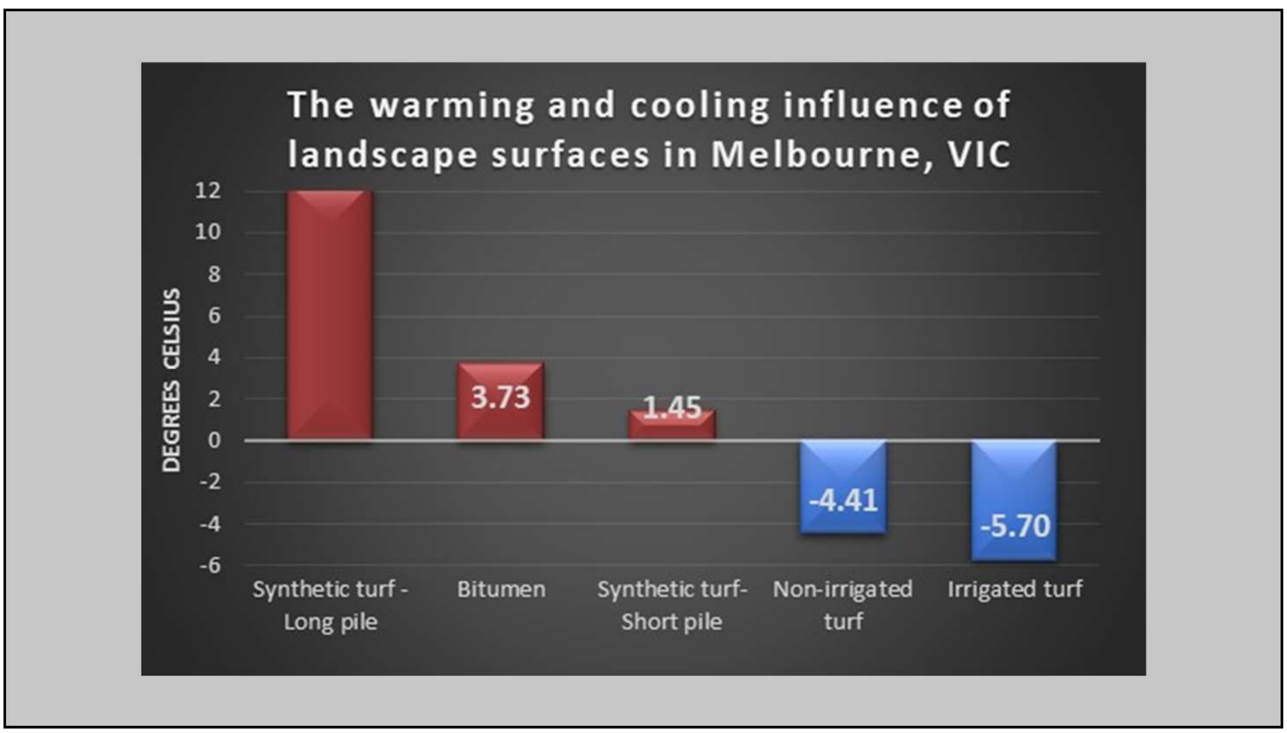
19

Surface type	Description	Examples
Irrigated living turf	Areas of green healthy living turf with visual irrigation patterns	Golf courses, sports fields, reserves, gardens
Non-irrigated living turf	Areas of maintained vegetation with no evidence of irrigation	Reserves, sports fields surrounds, non-irrigated areas of golf courses
Synthetic turf – long pile	Large fields of synthetic turf playing surfaces	Hockey clubs, futsal fields
Synthetic turf – short pile	Thin synthetic turf coverings	Yardscapes, cricket nets
Bitumen	Dark hardscaped driving surfaces	Parking lots, roads

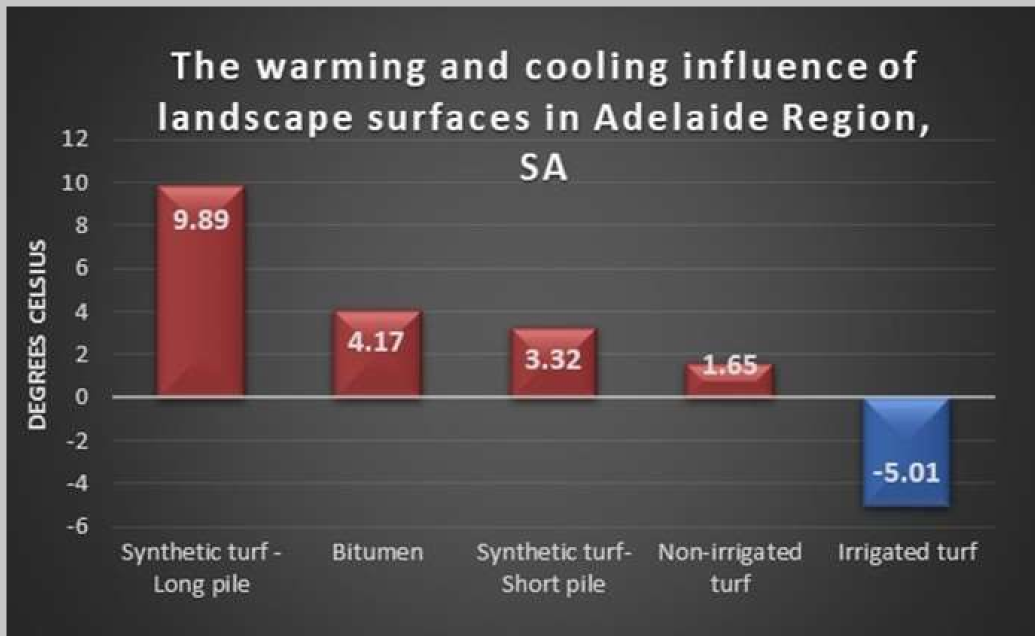
20


The warming and cooling influence of landscape surfaces in Parramatta, NSW
DEGREES CELSIUS
12
10
8
6
4
2
0
-2
-4
-6
10.51
6.27
4.88
-1.49
-3.83
Synthetic turf - Long pile
Bitumen
Synthetic turf- Short pile
Non-irrigated turf
Irrigated turf

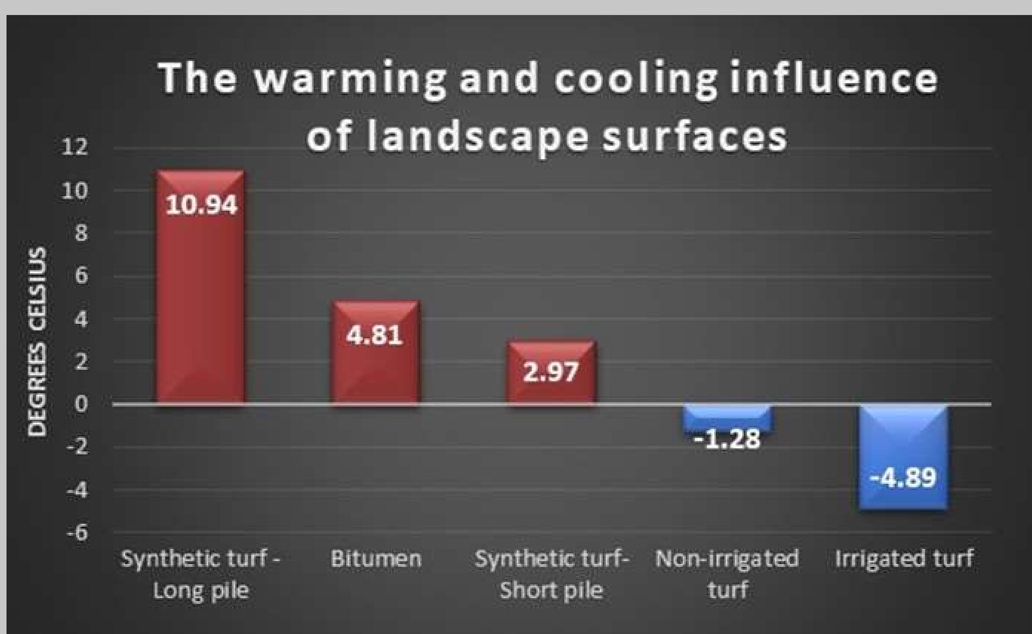
21


The warming and cooling influence of landscape surfaces in Melbourne, VIC
DEGREES CELSIUS
12
10
8
6
4
2
0
-2
-4
-6
3.73
1.45
-4.41
-5.70
Synthetic turf - Long pile
Bitumen
Synthetic turf- Short pile
Non-irrigated turf
Irrigated turf

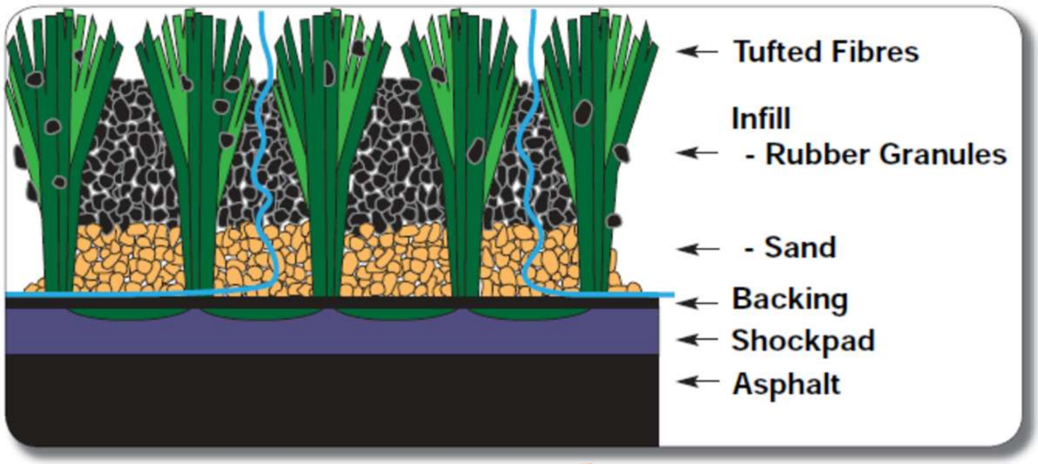
22


The warming and cooling influence of landscape surfaces in Adelaide Region, SA
DEGREES CELSIUS
12
10
8
6
4
2
0
-2
-4
-6
9.89
4.17
3.32
1.65
-5.01
Synthetic turf - Long pile
Bitumen
Synthetic turf- Short pile
Non-irrigated turf
Irrigated turf

23

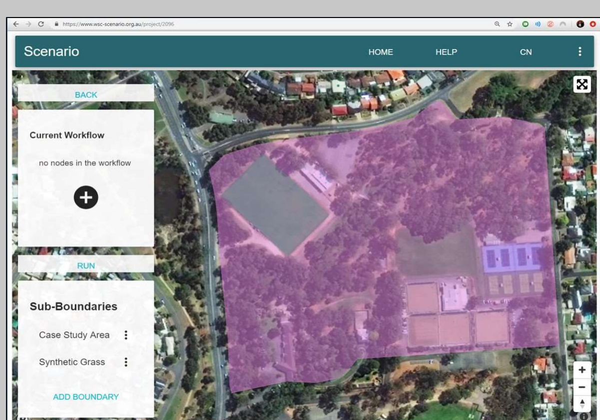

The warming and cooling influence of landscape surfaces
DEGREES CELSIUS
12
10
8
6
4
2
0
-2
-4
-6
10.94
4.81
2.97
-1.28
-4.89
Synthetic turf - Long pile
Bitumen
Synthetic turf- Short pile
Non-irrigated turf
Irrigated turf

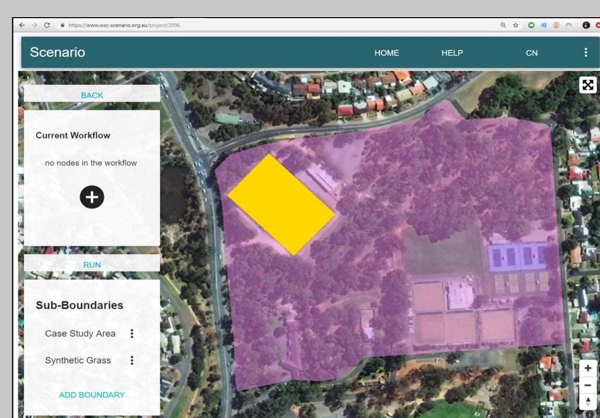
24



Short pile < 12 mm, medium pile 20-35 mm, long pile 35-60 mm

25

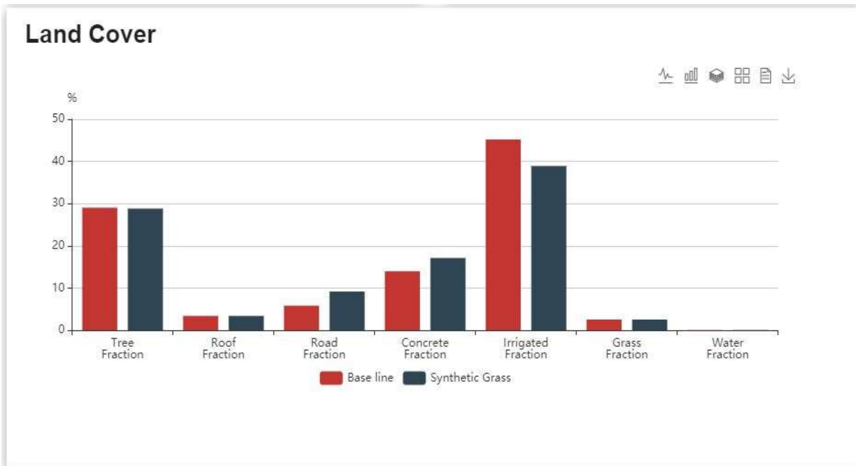




CRC for Water Sensitive Cities – Scenario Tool

https://watersensitivecities.org.au/solutions/water-sensitive-cities-scenario-tool/

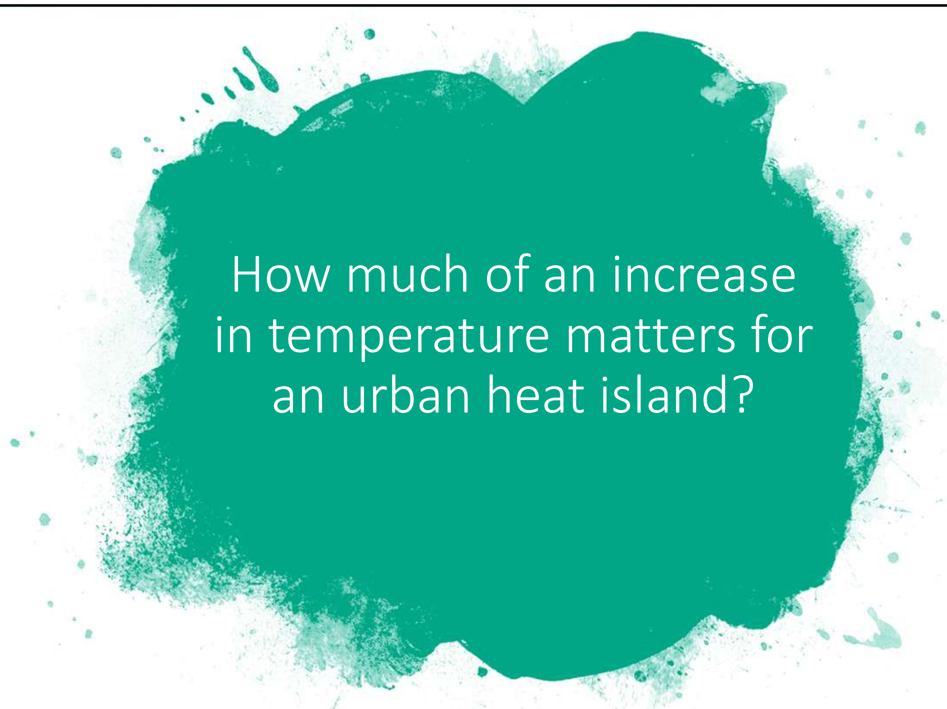
26



Land Surface Temperature

Scenario	Average Surface Temp... °C
Base line	41.99
Synthetic Grass	43.05

27



28

Surface to air temperature

29

Playing court example from Parramatta, NSW (12 Feb 2019).

Synthetic turf example from Port Phillip, VIC (03 Feb 2019).

30

Non-irrigated natural turf example from Port Phillip, VIC (03 Feb 2019).

Bare ground example from Adelaide, SA (02 Feb 2019).

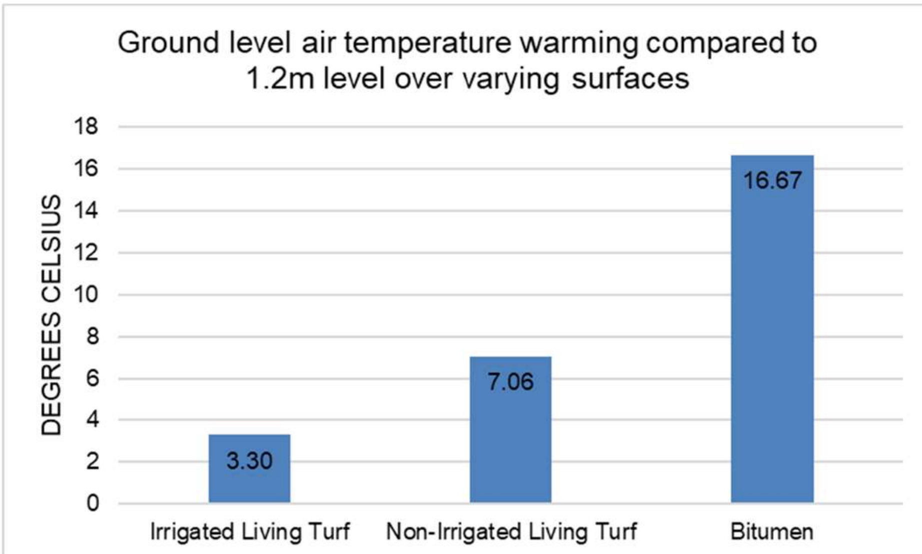
31

Surface to air temperature relationship

Air temperatures over the 15 transects showed an average maximum increase of 0.81 °C compared with nearby irrigated living turf

Average UTCI values were very consistent across the 15 transects ranging between 40 and 45 °C

32



33

Thermal comfort and energy use simulations

34

	Normal Weather – Cooling Energy (kWh/m2)	Shifted Weather – Cooling Energy (kWh/m2)	% Increase in Cooling Energy
Sydney	18	30	51%
Adelaide	13	20	48%
Melbourne	6	10	72%

Annual cooling-only energy increase resulting from urban heat islands

	Normal Weather – Cooling Utility Cost ($/m2)	Shifted Weather – Cooling Utility Cost ($/m2)	% Increase in Cooling Utility Cost
Sydney	$5.0	$7.6	51%
Adelaide	$5.1	$7.5	48%
Melbourne	$1.9	$3.3	72%

Annual cooling-only energy cost increase resulting from urban heat islands

35

Climate change

36

City	Temperature Change (2090, RCP 8.5)	Precipitation Change (2090, RCP 8.5)	Solar Radiation Change (2090, RCP 8.5)
Adelaide	2.9 °C	-9 %	1.5 %
Brisbane	3.7 °C	-16 %	0.8 %
Melbourne	3.0 °C	-9 %	3.1 %
Perth	3.5 °C	-18 %	1.0 %
Sydney	3.7 °C	-3 %	1.3 %

Changing capital cities

37

What will climate change mean for UHIs?

Widespread warming of all surfaces is unlikely to change the number and size of urban heat islands.

What will change is the frequency and severity of extreme heat events, the impacts of which will be experienced to a much greater extent within urban heat islands.

While thermal response of many surfaces will be similar under a changing climate, some surfaces may have different thermal responses.

38

Thermal performance changes

- Non-irrigated grass
  - During wetter periods and in wetter climates, non-irrigated grass performs similarly to irrigated grass providing a cooling effect.
  - During drier periods and in drier climates its surface temperature is close to bitumen and provides a strong warming effect.
- Irrigated turf
  - Will become more important for cooling in the future
  - Will require greater irrigation to provide cooling benefits

39

Summary

40

So what do the results mean for:

- Parks and reserves
- Homes
- Street verges

41

Summary

- Irrigated green space cools our cities
- Living turf is one of the coolest land surface types in our cities
- But, more green cover is being replaced with impervious surfaces
- The decisions we make today about how our cities are constructed influences how cool they will be now and in the future

42

Hort Innovation
Strategic levy investment
TURF FUND

Acknowledgements

The project team consisted of Seed Consulting Services (now Edge Environment), EnDev Geographic and Atelier Ten. The project team recognises the funding support of Hort Innovation for this project and the assistance provided by Turf Australia in providing feedback on project deliverables and for assisting with connecting with its network of members for extension activities. The Project Team recognises and thanks the following organisations for the assistance they provided during the project:

Provision of surface temperature data: New South Wales: City of Parramatta; Victoria: City of Port Phillip; South Australia: AdaptWest region councils (City of Port Adelaide Enfield, City of Charles Sturt, City of West Torrens), City of Salisbury and the Resilient East region councils (City of Adelaide, City of Burnside, City of Campbelltown, City of Norwood Payneham St Peters, City of Prospect, City of Tea Tree Gully, City of Unley, and Town of Walkerville).

Field sites: New South Wales: City of Parramatta; Victoria: City of Port Phillip, Moreland City Council; South Australia: Adelaide High School

Support in the organisation of the national seminar series: Adelaide – City of Charles Sturt, AdaptWest region of councils; Brisbane – Brisbane City Council, Turf Queensland; Melbourne – City of Monash; Perth – University of Western Australia, Turf Western Australia, Cooperative Research Centre for Water Sensitive Cities; Sydney – South Sydney Region of Councils.

43

Hort Innovation
Strategic levy investment
TURF FUND

Thank you

For further information please contact:

mark.siebentritt@seedcs.com.au

44