Alice Springs Heat Mitigation Study

UNSW

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Final Report
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INTRODUCTION

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Alice Springs Heat Mitigation Study
Introduction

Contents and Acknowledgements

This document presents the mitigation study for the CBD area of Alice Springs, performed by the High Performance Architecture Group of UNSW, Faculty of Built Environment.

The first part of the report includes the methods and the results of the terrestrial and aerial monitoring campaign, the assessment of the local overheating and finally the main conclusions on the climatic context characterised with the monitoring.

The second part presents initially an introduction to the various available mitigation technologies, and then the methodology and the results of the considered unmitigated – namely the present condition – and mitigated scenarios. Advanced simulation techniques have been used and the distribution of the ambient temperature, surface temperature and wind speed have been fully calculated. The air temperature has been normalized to standard pressure conditions (referred to as potential temperature), to allow comparisons between the conditions at different elevations and in different scenarios. The spatial distribution of the potential temperature decrease has been calculated for each scenario.

The last part of the document includes the proposed specifications for each of the mitigation scenarios, as well as the conclusions of the study.

We thankfully acknowledge the Northern Territory Government for funding this research activity and the technical and logistic support offered during the monitoring campaign. We are particularly grateful to the Chief Minister Michael Gunner and Sabine Wedemeyer (Director of Policy Coordination and Implementation of the Southern Region, Department of the Chief Minister).

We would like to express our thankfulness to Dan Gerich of Uberair for conducting and managing the aerial survey and to Geraldo Sansone of Skymonkey for the post-processing of aerial data.
EXECUTIVE SUMMARY

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Alice Springs Heat Mitigation Study
Executive Summary

Introduction

The local climate in the built environment exhibits peculiar features, differentiating it from the climate conditions at adjacent non-urban areas. This happens as local climate results from the interaction between land and/or water surface and the atmosphere, as well as of the climate forcing.

One of the most documented climate phenomena is the urban heat island (UHI) effect, namely the local overheating in the built environment, with higher ambient temperatures than in the adjacent surroundings. This is documented for hundreds of cities around the world including major cities in Australia and it adds to and interacts with the global climate change. The impacts on thermal comfort, energy consumption, and health is serious with relevant immediate consequences on the local economy.

Several mitigation technologies have been thoroughly tested and proved effective with research and trials carried out in Australia and overseas. The main mitigation technologies are:

- **Cool materials**. They reflect most of the incident sunlight and they cool as they mostly release heat as thermal radiation, thus retaining low surface temperatures even under the sun. Materials that instead absorb solar radiation (e.g., dark asphalt) convert that energy into heat and reach high surface temperatures. Hot surfaces overheat the built environment as the heat is transferred (mostly) by convection to the urban atmosphere;

- **Urban shading devices**. Engineered shading with high performance materials reflect the sunlight towards the sky before it enters the urban canopy, preventing it to reach the most absorbing surfaces in the built environment (e.g., the asphalt concrete of street pavements) and providing shelter to people from the solar radiation.

- **Water based technologies**. Fountains, ponds and water sprinklers use a great amount of energy for water evaporation (therefore this energy is not converted into heat).

- **Greenery**. Vegetation typically retains a surface temperature close to the ambient temperature, as it uses a good fraction of solar radiation for photosynthesis, morphogenesis and other biological processes, including the complex of evaporation and transpiration (and that energy is not converted into heat). However, beyond a temperature threshold – which is typical for each species and usually in the range of 36 °C – to preserve water and survive the plants reduce the biological processes that release water vapour and even drop the leaves at higher temperature ranges.

- **Tree planting**. Trees couple the effect of vegetation with that of shading.

These technologies, when properly implemented in different combinations and arrangements specific to the context, have been demonstrated as effective to decrease the ambient temperature and counterbalance the impact of the urban heat island effect.
This report investigates the characteristics of the local climate of Alice Springs, NT, identifies hot spots in the city, to develop and evaluate appropriate local climate mitigation scenarios and propose optimum solutions, tailored for the city of Alice Springs. To achieve these objectives, a first set of climate simulations was performed to identify the hot spots. Then, a monitoring campaign was performed in the CBD of Alice Springs, including an aerial survey over six areas (with infrared images captured by a drone) and terrestrial survey at 35 points (with air temperature, humidity, wind speed and direction, and radiation measurements). The measurements were used to calibrate the climate model, to robustly represent the unmitigated scenario and mitigated conditions were simulated consequently. Finally, the climatic evaluation of the developed mitigation scenarios has been carried out to compare with the existing situation in Alice Springs CBD and specific mitigation solutions proposed for implementation.

The following activities have been carried out:

- Experimental campaign involving aerial infrared monitoring using drone technologies and terrestrial monitoring of meteorological parameters to investigate the climate response features of the built environment in Alice Springs.
- Identification of the hot spots in the city and development of appropriate mitigation scenarios
- Climatic evaluation of the developed mitigation scenarios compared to the existing situation in Alice Springs, using advanced simulation techniques and proposal for the optimum mitigation solution to be implemented
A two-day ground and aerial survey was conducted in order to get real time thermal and meteorological data useful to recreate the contingent Urban Heat Island amplitude and characteristics. The main goals were:

- To capture aerial thermographic images of the pavements, streets, buildings facades and roof surfaces by utilizing an Unmanned Aerial Vehicle (UAV=drone) equipped with a thermal camera;
- To collect meteorological data all along the hot spots of Alice Springs CBD.

The UAV survey took place on the 19th of October from 9am to 2pm and on the 20th of October between 10am and 12pm. Six areas were surveyed with the drone (Figure 1), capturing thermal images and videos that were post-processed and analysed to quantify the surface temperatures in the built environment of Alice Springs.

![Figure 1. Alice Springs aerial monitoring campaign. Drone surveyed areas.](image)

Considering for example the area of Parsons St (Figure 2), it was found that the surface temperature of sunlit streets ranges between 61 °C and 68 °C, slightly lower for sidewalks (i.e., 58-65 °C), while shadowed portions of street and sidewalks range between 45 °C and 60 °C, depending on the effectiveness of the shadowing provided by the trees. Tree canopies show a surface temperature ranging between 38 °C and 45 °C, while green areas between 36 °C and 40 °C. Reflective roofs, show a surface temperature in the range of 36-40 °C, too. The average difference in surface temperature between street pavements and green areas or reflective roofs is thus of the order of 22-24 °C. Similar figures were observed at the other surveyed areas (Figure 3).
The terrestrial survey was designed to map the meteorological conditions characterizing Alice Springs CBD in terms of air temperature, relative humidity, wind speed and direction, solar radiation and thermal radiation fluxes at 35 locations (Figure 4). At each location, measurements were conducted for a period of 10 minutes (Figure 5).
Figure 4. Terrestrial monitoring: measurement points in Alice Springs.

Figure 5. Example of the measured values at Parson St and Terrace.

The maximum UHI intensity, considered as the difference in air temperature figures, is 2.6°C and is recorded in the innermost side of the CBD (Figure 6). However most of the measured points show no evident UHI effects; some of them result even cooler than the BoM baseline (points aligned on the boundary between the two areas of interest). Some local hot spots are detected where asphaltic streets and red sand parking lots are dominant. The wind speed is much reduced in the CBD,
compared to the airport values, even by 8 m/s at some locations during the second day of the monitoring. The relative humidity, as a general trend, is higher in the CBD than at the airport, but is in general very low, and lower than 20% between 10 am and 5 pm of a hot day with low wind speed and a temperature of 35-37 °C.

To reduce urban overheating and mitigate the consequences of the urban heat island effect like thermal discomfort in outdoor and indoor non-airconditioned spaces, increased energy consumption for cooling and peak loads, increased air pollution and emission of greenhouse gasses, increased rates of heat related mortality and morbidity and of course increased related expenses, urban heat island mitigation strategies have been proposed. Some of the most successful and applied technologies are outlined below:

- **Cool roofs and pavements** increase the albedo (solar reflectance) of urban surfaces preventing solar radiation from being absorbed. Surfaces stay cooler under the sun releasing less heat into the ambient air.
- **Street shading** reduces solar radiation from reaching the street level providing a cooler environment.
- **Tree planting** can improve thermal comfort condition and decrease local ambient temperatures by protecting the city from hot winds on Eastern and South-Eastern side of the CBD.
- **Fountains, ponds and sprinklers** provide improved thermal comfort by cooling the air through the evaporation process of water and by using water bodies as heat sinks.
To study countermeasures to local overheating, a climate model was calibrated with the measured values using as boundary conditions the airport data, assessing then the mitigation potential in different scenarios. Simulations have been performed using the software ENVI-met V4.1.3, namely a three-dimensional microclimate model designed to simulate the surface, plant and air interactions in an urban environment. Simulations have been performed for a representative warm summer day, with ambient temperature corresponding to the 90% of the long-term records. The corresponding climatic data are taken from Bureau of meteorology station located in Alice Springs Airport. The simulated area is located approximately 12 km from the BoM station. The average daytime outdoor temperature for the representative warm summer day in 2017 was taken as 32.5 °C and the relative humidity was 40%. The simulated area is of approximately 2 km² (Figure 7), and it includes all the measurement locations plus a boundary area.

Based on specific climatic characteristics and the identified overheating and thermal comfort problems in Alice Springs, five mitigation scenarios have been designed aiming to decrease the ambient temperature in Alice Springs (Table 1). The spatial distribution of the ambient temperature in the whole CBD area, as well as the distribution of the surface temperature, the wind speed and direction have also been calculated in detail for each scenario.
Table 1. Description of the defined mitigation scenarios

<table>
<thead>
<tr>
<th>N</th>
<th>Description of scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reference Model: Albedo of walls and roofs=0.2, Asphalts Albedo=0.05, Concrete pavements=0.15</td>
</tr>
<tr>
<td>2</td>
<td>Cool material: Global albedo of building=0.6, Global albedo of pavements=0.5</td>
</tr>
<tr>
<td>3</td>
<td>Shading: Albedo of streets (Asphalt)=0.91, Albedo of concrete pavement=0.92</td>
</tr>
<tr>
<td>4</td>
<td>Wind break: Planting 121 mature trees to protect the city from hot winds</td>
</tr>
<tr>
<td>5</td>
<td>Water fountain: Application of 56 water fountain in the CBD</td>
</tr>
<tr>
<td>6</td>
<td>Combined Scenario: Wind break, Shading, Water fountain, Cool material</td>
</tr>
</tbody>
</table>

The main results for each scenario are outlined below:

- **Reference scenario**: The ambient temperature varies between 35.0 °C -42.3°C in Alice Springs for wind speeds of 4m/s. The maximum surface temperature of asphalt pavements (parking area) is 63.8 °C.
- **Increase of the reflectivity of the city to a global albedo of 0.5 (pavements) and 0.6 (buildings)** results in a maximum local temperature drop of about 2.9°C in the CBD area for the wind speed of 4 m/s. The ambient temperature ranges from 34.8°C to 41.1°C (SE wind, 4m/s). The maximum surface temperature drops by 4.6°C reaching a value of about 59.2 °C.
- **Solar Control of the Main Streets in Alice Springs**: Reducing incident solar radiation on streets and car parks by 90% via shading, results in a maximum temperature drop in the CBD area of about 4.8°C for the wind speed of 4 m/s. The ambient temperature ranges from 35.6°C to 41.3°C in the shaded area. The maximum local surface temperature reduction is 26.3 °C.
- **Tree planting to provide wind break on the eastern side of Alice Springs**: Planting 121 mature trees to protect the city from hot winds results in a maximum local temperature drop of 1.7°C. The temperature reduction effect in the whole CBD area for this mitigation strategy is almost negligible. Since this intervention has local effect, there is up to about 0.90-11.22°C reduction in the surface temperature where additional trees are added.
- **Water-Evaporative Cooling**: The application of 56 water fountains in the Todd Mall results in a maximum local temperature drop of 2.9 for the wind speed of 4m/s. The temperature reduction effect in the whole CBD area for this mitigation strategy is almost negligible.
- **Combined scenario**: The use of reflective materials for walls, roofs and pavements, the application of shading in specific zones of the city, use of water and wind break results in a maximum temperature drop of approximately 15.9°C for the SE winds at a wind speed of 4m/s. The ambient temperature ranges between 24.7-41.1 °C (SE-4m/s). The surface temperature drop mainly varies from about 12.5 (°C) to 24.0 (°C) in the areas where shading devices and water fountains were applied (Figure 8).
Table 2. Summary of the mitigation results.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$T_{AIR,AVG}$ ($^\circ$C)</th>
<th>$T_{AIR,MAX}$ ($^\circ$C)</th>
<th>$T_{AIR,MIN}$ ($^\circ$C)</th>
<th>$\Delta T_{AIR,AVG}$ ($^\circ$C)</th>
<th>$\Delta T_{AIR,MAX}$ ($^\circ$C)</th>
<th>$\Delta T_{AIR,MIN}$ ($^\circ$C)</th>
<th>Max$^*$ $T_{AIR}$ ($^\circ$C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>39.0</td>
<td>42.3</td>
<td>35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wind break</td>
<td>39.0</td>
<td>41.9</td>
<td>35.1</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Cool materials</td>
<td>38.1</td>
<td>41.1</td>
<td>34.8</td>
<td>0.8</td>
<td>1.2</td>
<td>0.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Water</td>
<td>38.7</td>
<td>42.3</td>
<td>26.5</td>
<td>0.3</td>
<td>0.0</td>
<td>8.5</td>
<td>13.8</td>
</tr>
<tr>
<td>Shading</td>
<td>38.8</td>
<td>42.3</td>
<td>35.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Shading-shaded area**</td>
<td>37.3</td>
<td>41.3</td>
<td>35.6</td>
<td>1.1</td>
<td>0.1</td>
<td>0.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Combined</td>
<td>37.7</td>
<td>41.1</td>
<td>24.7</td>
<td>1.3</td>
<td>1.2</td>
<td>10.3</td>
<td>15.9</td>
</tr>
</tbody>
</table>

Notes: *Maximum temperature decrease achieved based on the scenarios compared to the reference model. ** Ambient temperature and reduction of the ambient temperature (K) is given for the local scale where mitigation strategy was employed.

Figure 8. Ambient temperature reduction in the combined scenario compared to the unmitigated scenario subject to the same conditions (maximum reductions exceeding 2.8 °C are not highlighted in the plot).

Conclusions

Five mitigation scenarios involving UHI mitigation strategies such as use of reflective materials for buildings and pavements, street shading, wind break and evaporative systems have been designed aiming to decrease the ambient temperature in Alice Springs. Advanced simulation techniques have been used to quantitatively evaluate their UHI mitigation impact. The results have shown that the proposed mitigation technologies can decrease the maximum ambient temperature from 42.3 °C to 41.1 °C. In parallel, the minimum ambient temperature in the area can decrease from 35.0 °C to 24.7°C. The achieved decrease of the maximum ambient temperature is close to 1.2°C, while the
corresponding decrease of the minimum temperature is close to 10.3 °C compared to the reference scenario representing the actual situation.

The maximum temperature drop is achieved through the combination of the various mitigation technologies, while the minimum performance corresponds to the use of only wind break. Some of the considered mitigation scenarios (mainly evaporative systems and shading), which are implemented in specific zones and not in the whole CBD area, were shown to have a significant maximum local temperature reduction, although their mitigation impact for the whole CBD area is very low or even zero.

The considered mitigation technologies contribute to decrease considerably the surface temperature in the CBD area. The range of surface temperature reduction is found to be between 1°C and 30 °C. The maximum surface temperature drop is achieved when shading, cool pavement technologies, and combination of technologies are implemented. The local reduction of the surface temperature produced by these technologies may exceed 26°C. Lower surface temperatures correspond to improved thermal comfort levels as the emitted infrared radiation and the heat transferred by convection from the opaque surfaces is significantly reduced.