Horticulture Innovation Australia

Final Report

Greening Neighbourhoods - Mitigating Heat Stress with Vegetation

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CSIRO Climate Adaption Flagship

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Summary

In Australia's major cities, population growth and rapid development has led to the transformation of many urban landscapes, resulting in engineered infrastructure dominated by heat absorbing surfaces. This heat accumulation can cause the ambient temperature in urban areas to be several degrees higher than that of nearby rural areas, known as the urban heat island (UHI) effect. In summer, the risk of heat-related health impacts in urban areas may be further exacerbated by climate change, as heat waves are projected to increase in frequency, intensity and duration. These multiple and interacting factors present enormous challenges for governments, industries and communities.

This project explored the potential benefit of urban green infrastructure in mitigating extreme summer temperatures and reducing heat-related health impacts by providing tree shade to streets and buildings and by ambient cooling through evapotranspiration of vegetation. The heat mitigating potential of different vegetation schemes was investigated using three scales of analysis, i.e. suburb, neighbourhood and household. Western Sydney was the geographic focus for the research due to its heat vulnerability.

The research was undertaken using computer modelling, for three suburb centres in Western Sydney: Parramatta, Penrith and Campbelltown. The urban scale modelling results suggest that cooling benefits of various urban forms and vegetation schemes may be in the range from 0.5°C by doubling the amount of vegetation up to around 2°C if the area is covered with forest parklands. Based on the correlations established between the historical mean daily air temperature and hospital admission rates for dehydration (DEHY) and heat exposure (HEAT), the potential benefit of urban greening in reducing heat-related hospital admission rate were estimated. When compared to the existing Parramatta CBD, a leafy urban suburb was estimated to reduce the projected daily hospital admission rates for DEHY and HEAT by 15% and 30%, respectively.

With the current climate in Western Sydney, in order to achieve the best balanced performance in reducing both heat-related health risk and total annual energy requirements for heating and cooling of houses, trees should be arranged to the east and west of the house, while trees to the north should be avoided. However, trees to the north and north-west will benefit both heat stress mitigation and total heating and cooling energy requirement reduction when the climate gets warmer in 2030 and 2070.

The research findings can be valuable to local councils and urban developers for more resilient urban designs, to householders for planting trees and vegetation strategically positioned for mitigating heat wave impact. The research methodologies developed may be relevant to other urban areas in Australia.

Keywords

Urban vegetation; urban heat island; heat waves, thermal stress, hospital admission, tree shading, climate change

Introduction

Heat waves are recognised as one of Australia's most significant natural hazards, killing more people than any other type of natural disaster (PwC, 2011; State of Australian Cities, 2013). The heat wave in Melbourne, Australia, during the summer of 2009 was attributed as the cause of hundreds of excess deaths and an eight-fold increase in heat-related presentations to hospital emergency departments (DHS, 2009). Similarly, the Sydney heat wave in 2011 saw heat-related presentations to emergency departments increase seven-fold over what would have normally been expected (Schaffer et al. 2012).

The risk of summer heat stress is likely to be exacerbated in urban Australia by two factors: the urban heat island effect which exacerbates heat wave events by trapping and storing heat in existing urban areas (DSE 2002, NSW DoP 2010) and more frequent, severe and longer lasting heat wave events associated with global warming (Alexander and Arblaster 2008). As such, these interacting factors present significant environmental and social challenges for governments and communities around the world as they attempt to manage heat-related health impacts (Luber 2008; Wu and Yang 2013). Urban greening has attracted substantial research and community interest as a possible solution. Greening can modify the urban heat island effect by providing tree shade to buildings and urban infrastructure, and by cooling the air through the evapotranspiration of vegetation (Wong and Lau 2013; Chen et al. 2015).

Co-funded by Horticulture Australia Limited using the Nursery Industry Levy and CSIRO Land and Water, the Greening City project (project # NY11013) commenced research on mitigating heat stress with urban vegetation in 2011. The project has provided further research evidence in support of urban vegetation as one of the most important strategies for mitigating extreme heat. Quantitative estimates of the potential impact of various urban vegetation schemes in reducing extreme urban temperature were generated, demonstrating that vegetation can reduce excess mortality rate associated with heat stress (Chen, 2012a; Chen et al . 2012; Chen and Wang 2012; Chen, 2012b). The research findings have attracted broad interest from governments, city councils, research institutes and related industries.

The heat mitigation effect identified in the Greening City project is an average effect over a relatively large urban scale. The current project is designed for an overall evaluation of vegetation effect at the metropolitan scale. Optimisation of tree and vegetation schemes and designs at urban, neighbourhood and individual building scales offers further potential for heat stress mitigation, particularly through targeting hot landscapes and buildings. Extreme heat is likely to have a significant effect on Western Sydney resulting from its topography and distance from sea breezes (DECCW, 2010). This project carried out detailed modelling investigations to demonstrate how appropriate vegetation schemes at different scales can be used to mitigate heat waves and reduce vulnerability in Western Sydney suburbs.

Methodology

A multi-scale numerical modelling approach was used, which involved a downscaled climate model (TAPM-UCM), an intermediate-scale computational fluid dynamics (CFD) model, and a building thermal modelling tool (AccuRate). TAPM-UCM was used for modelling the suburb scale, CFD for modelling the neighbourhood scale, and AccuRate for modelling the building scale. At each scale, the potential impact of different vegetation schemes on indoor/outdoor thermal comfort and heat stress were investigated.

The project included the following six major activities.

1) Western Sydney Hot Spots

   Satellite thermal infrared imagery were obtained from GeoSciences Australia for the 2011 Sydney summer heat wave. Based on satellite and high-resolution aerial thermal imageries, hot spots in the Western Sydney region were identified as the basis for more detailed investigations.

2) Suburb Vegetation Schemes

   TAPM-UCM was used for the three selected suburbs in Western Sydney – Parramatta, Penrith and Campbelltown. Suburb micro-climate was modelled for current (2011) and projected future climate (2030 and 2050) assuming various suburb vegetation schemes, including different park arrangements, tree canopy coverage, etc. The simulation resolution of TAPM-UCM is down to a limit of 1km×1km grid. The simulation results from TAPM-UCM provided input for the neighbourhood scale CFD modelling which has a nominal domain dimension of 500m × 500m.

3) Neighbourhood Vegetation Arrangements

   Using computational fluid dynamics software, with the boundary conditions obtained by TAPM-UCM simulations, one selected hot spot area was modelled under two different urban vegetation schemes, to examine the impact on local extreme temperatures for the 2011 heat wave period.

4) Tree Shade and Building Performance

   The impact of tree shading was modelled using AccuRate for three sample houses in Western Sydney for a base climate (2000) and future climates in 2030 and 2070. Simulations of building performance were undertaken for a total of 30 different tree shade scenarios to test the influence of different tree life forms, tree size, canopy porosity, and the direction and distance of trees relative to the building. Recommendations were provided based on the simulation results.

5) Hospital Admissions and Temperature

   The impact of heat stress on excess hospital admission rate was quantified for Western Sydney area using historical data. Combining with urban climate model simulation results, the potential of vegetation in reducing heat-related hospital admissions in Western Sydney was investigated.

6) Publish and Disseminate Research Findings

   The findings of this project were disseminated in relevant conferences such as climate change, urban planning, and industry conferences. Several journal papers were published based on the findings of the research project. Two targeted workshops were convened in Sydney for the purpose of communicating with urban decision makers in industry, government and community.

Outputs

Chen, D., Thatcher, M., Wang, X.M., Barnett, G., Kachenko, A. Prince, R., 2013. Urban Vegetation for Reducing Heat Related Mortality, in proceedings of Urban Environmental Pollution Conference, 17-20 November 2013, Beijing, China. ***The paper was award for the best scientific paper in the Urban Environmental Pollution Conference 2013, Beijing, China.***

Ren, Z.G., Chen, D., Barnett, G., Wang, X.M., 2014. Indoor Heat Stress Mitigation with Urban Vegetation and Tree Shading, *Nursery Paper*, Aug. 2014 Issue No.7.

Chen, D., Barnett, G., Meyers, J., Beaty, M., Han, J. and Lipkin, F., 2014. Potential of Vegetation in Mitigating Heat Stress in Western Sydney, *report to HAL*, Feb 2014.

Chen, D. 2014. Greening Neighbourhoods - Mitigating Heat Stress with Vegetation, project summary for Nursery Industry Advisory Committee Annual Report 2013/14.

Ren, Z.G., Chen, D., Barnett, G., Wang, X.M., 2014. Impacts of tree planting on indoor heat stress in Australia, in proceedings of *Climate Adaptation 2104*, 30 Sept- 2 Oct 2014, Gold Coast Convention and Exhibition Centre, Gold Coast, Queensland.

Greening urban areas can help reduce future impacts of heat waves, CSIRO media release, 2014.

Chen, D. 2014. Mitigating Extreme Summer Temperatures with Vegetation, poster presentation in the 29th International Horticultural Congress 2014, Brisbane, Australia.

Co-organised a workshop on “A strategy for urban green infrastructure and climate adaptation research in Australia”, Crowne Plaza, Coogee Beach, Sydney, 16th – 17th September, 2014.

Chen, D., Wang, X.M., Thatcher, M., Barnett, G., Kachenko, A. Prince, R., 2015. Urban Vegetation for Reducing Heat Related Mortality, Environmental Pollution 192, 275-284. ***This paper was selected in the Summer Special of Elsevier’s Research Selection.***

Chen, D., Wang, X.M., Thatcher, M., Barnett, G., Kachenko, A. Prince, R., 2015. Summer cooling potential of urban vegetation—a modeling study for Melbourne, Australia, *AIMS Environmental Science* (DOI: 10.3934/environsci.2015.3.648).
http://www.aimspress.com/aimses/ch/reader/view_abstract.aspx?file_no=Environ2015053&flag=1

Tong, S.L., Wang, X.Y., Yu, W.W. Chen, D., Wang, X.M., 2014. The impact of heatwaves on mortality in Australia: a multi-city study, *British Medical Journal Open* 2014/02/20 ed. pp. e003579.

Wang, X.Y., Guo, Y.M., FitzGerald, G., Aitken, P., Tippett, V., Chen, D., Wang, X.M., Tong, S.L., 2015. The impacts of heatwaves on mortality differ with different study periods: a multi-city time series investigation, *PLOS ONE*, in press.

Co-organised a workshop on “A national strategy for urban green infrastructure research”, Crowne Plaza, Coogee Beach, Sydney, 20th July - 21st July, 2015.

Outcomes

This is the first time that an integrated approach was used for the investigation of benefit of urban greening in reducing urban heat stress using three different scales, i.e., suburb, neighbourhood and individual buildings. This research project and findings were acknowledged in the greening infrastructure and climate change adaptation communities in Australia as well as internationally.

The research findings present quantitative estimations of the benefits of vegetation in mitigating heat stress in suburb, neighbourhood and individual building scales. The findings have been disseminated in two Australian conferences, two international conferences, and acknowledged via two green infrastructure workshops organised by CSIRO during the project period. The results provide direct visualised links between vegetation level, heat stress and potential in reducing hospital admission rate in Western Sydney. The findings further strengthen the importance of proper urban vegetation designs in urban planning to mitigate heat-related health impacts and add support to the 202020 Vision program.

Research findings were presented in the Urban Environmental Pollution Conference, 17-20 November 2013, which was hold in Beijing, China. The findings were well received by the conference and was awarded the best scientific paper. It was subsequently invited to be published in the journal Environmental Pollution. This journal publication was later selected in the Summer Special of Elsevier's Research Selection.

In 2014, the research findings were cited in the "Growing Green Guide – Victoria's Guide to Green Roofs, Walls and Facades" (http://www.growinggreenguide.org/wp-content/uploads/2014/02/GGG-research-section-17-dec.pdf).

Research activities in green infrastructure have been identified as one of the strategic research areas for CSIRO and has gained strong support from senior leadership. Research findings were included in a CSIRO media release on urban greening in mitigating heat wave impact (https://blogs.csiro.au/climate-response/stories/greening-urban-areas-can-help-reduce-future-impacts-of-heat-waves/).

Two workshop on greening infrastructure were organised by CSIRO in Sydney, the first in September 2014 and second in July 2015. The workshops brought together leading research institutes, industry, and government practitioners to discuss the research gaps, needs, and priorities to advance green infrastructure research in Australia. The workshops identified and detailed a national research strategy for urban green infrastructure in the following five main areas: Attitudes/Perceptions to acceptance of green infrastructure; Effects on biodiversity under increasing urban intensification; Economic Valuation of green infrastructure; Development of metrics, models and tools to assess current green infrastructure levels and their potential in the future; Turning Research into Policy and Practice. The research findings contribute to the body of evidence and add weight to the strategic research areas that were identified.

Evaluation and Discussion

1) Western Sydney Hot Spots

The spatial relationship between mean residential land surface temperature and hospital emergency admissions for heat-related disorders were explored for the Sydney heat wave from 30 January to 6 February 2011. It was found that post office areas with land surface temperatures above the mean (>39.3°C) were more likely to result in hospital emergency admissions for dehydration and other direct heat-related impacts, particularly in populations 0-64 years of age. Based on this analysis, three hotspots of heat-related health impact were identified in Western Sydney. These were centred upon Penrith, Parramatta and Campbelltown.

2) Suburb Vegetation Schemes

TAPM-UCM simulations were carried out for the three selected suburbs, ie., Penrith, Parramatta and Campbelltown in the Western Sydney region to model suburb micro-climate in 2011 and projected future climate in 2030 and 2050 with various suburb vegetation schemes, such as parkland, tree canopy coverage etc. The average summer daily maximum temperature (ASDM temperature) over December, January and February were calculated for the three areas, using various vegetation schemes. In comparison with the existing CBD scheme, it was found that in terms of the averaged summer daily maximum temperature (ASDM temperature):

a. A relatively leafy suburb area may be around 0.1-1.0 °C cooler than the CBD area;
b. A parkland (such as grassland, shrub-land and sparse low forest) or rural area may be around 1.5 – 2.0 °C cooler than the CBD;
c. Doubling the CBD vegetation coverage may reduce around 0.5°C ASDM temperature;
d. 50% green roof coverage of the CBD area may result in 0.1-0.2°C ASDM temperature reduction.

The cooling benefit of parks comprising a structure of forest and shrub was predicted to be lower for Penrith and Campbelltown than for Parramatta. The reason is that Parramatta is a more urbanised city than both Penrith and Campbelltown. The urban heat island effect in Penrith and Campbelltown is thus weaker in comparison. Therefore, parks with a forest and shrub structure in Penrith and Campbelltown have relatively less impact on the local urban climate. Consistent with previous findings (Chen et al., 2015). It was also found that the relative impact on the ASDM temperature due to various urban forms and vegetation schemes under future climatic scenarios are similar to those predicted for the current climate. Therefore, the benefit of urban vegetation in the current climate will remain the same under future warming.

3) Neighbourhood Vegetation Arrangements

Neighbourhood scale computational fluid dynamics (CFD) modelling was used to assess the thermal environment impact of two vegetation schemes for Parramatta. Simulation results show up to 4.65°C reduction in the peak air temperature and an averaged 2.88°C reduction during the three day heat wave period in 2011 in Parramatta with a doubling of vegetation cover. During this research, it was found that CFD simulation at the neighbourhood scale has several major challenges: computing requirements are significant in order to resolve the detailed heat transfer to buildings and the ground soil; accurate history of soil moisture conditions and evapotranspiration is a required input, but is typically not available.

4) Tree Shade and Building Performance

The potential benefits of tree shade in reducing the heat-related health risk and cooling energy requirements of three typical Western Sydney houses were investigated using numerical building simulations using AccuRate for a base climate (2000) and future climates in 2030 and 2070. Simulations of building performance were undertaken for a total of 30 different tree shade scenarios to test the influence of different tree life forms (deciduous/evergreen), tree size, canopy porosity, and the direction and distance of trees relative to the building. It was found that tree shading to the east and west of the house under the 2000 climate achieves the best balanced performance in reducing both heat-related health risk and total annual energy requirements for heating and cooling. With climate change, however, the benefit of tree shade becomes more significant. The additional placement of trees to the north and north-west of the house is required in 2030 and 2070, to deliver the lowest energy requirement and lowest thermal discomfort. The results suggest that urban planners and building owners should consider tree shade as a climate change adaptation strategy, but careful attention is needed to ensure suitable trees are planted in the most appropriate locations. Tree shade, however, is not a panacea for poor performing housing and should be a part of broader building improvements.

5) Hospital Admissions and Temperature

Historical hospital admission and weather data were used to quantify the potential benefit of urban vegetation in reducing heat-related hospital admission rates in Western Sydney. This involved the use of a meso-scale urban climate model to simulate the average summer daily mean (ASDMean) temperature using ten different urban vegetation schemes. The vegetation schemes ranged from the current vegetation coverage level in Parramatta CBD through to leafy urban suburbs, to full revegetation schemes represented by sparse forest. Correlations were established between mean daily air temperature at Parramatta and hospital admission rates for dehydration (DEHY) and heat exposure (HEAT). The correlations were then applied to the modified climates to estimate the reduction in hospital admission rates due to changes in the ADSMean temperature for each of the ten vegetation schemes. The results show that hospital admission rates are expected to reduce with increased urban vegetation. When compared to the existing Parramatta CBD, a leafy urban suburb in Western Sydney was estimated to reduce the projected daily hospital admission rates for DEHY and HEAT by 15% and 30%, respectively.

6) Publish and Disseminate Research Findings

The findings of this project were disseminated in two domestic and two international conferences. Four journal papers were published during this research project. Two targeted workshop were also co-organised for communicating the research findings and for identifying future strategic research directions with those in industry, government and community groups.

Recommendations

1) During heat wave periods, public warning is required not only for populations 65 years plus, but also populations 0-64 years of age, particularly those who are undertaking outdoor activities.

2) Vegetation coverage in Western Sydney area can reduce the average summer air temperature up to 2 °C and should be considered as a heat wave mitigation strategy for urban planning. The benefit of increase vegetation coverage in reducing summer heat stress and heat-related hospital admission rates is greatest in the parts of the city that are the most heavily urbanised.

3) With the current climate in Western Sydney, shade trees to the east and west of a house provide the best balanced performance in reducing both heat-related health risk and the total annual energy requirements for heating and cooling.

4) In addition to trees at the east and west, it is recommended to plant trees to the north and north-west of houses in the near future since they will benefit both heat stress mitigation and total heating and cooling energy requirement reduction in houses with a warmer future climate.

5) CFD simulation at the neighbourhood scale has several challenges. These include the computer resources requirements; accurate history of soil moisture conditions and evapotranspiration; simulation of ground heat transfer.

Scientific Refereed Publications

Journal articles

Tong, S.L., Wang, X.Y., Yu, W.W. Chen, D., Wang, X.M., 2014. The impact of heatwaves on mortality in Australia: a multi-city study, *British Medical Journal Open* 2014/02/20 ed. pp. e003579.

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http://www.aimspress.com/aimses/ch/reader/view_abstract.aspx?file_no=Environ2015053&flag=1

Chen, D., Wang, X.M., Thatcher, M., Barnett, G., Kachenko, A. Prince, R., 2015. Urban Vegetation for Reducing Heat Related Mortality, *Environmental Pollution 192*, 275-284.

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IP/Commercialisation

None

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