Isolating the impacts of urban form and fabric from geography on urban heat and human thermal comfort

Kerry A. Nice, Negin Nazarian, Mathew J. Lipson, Melissa A. Hart, Sachith Seneviratne, Jason Thompson, Marzie Naserikia, Branislava Godic, Mark Stevenson

Transport, Health, and Urban Systems Research Lab
Faculty of Architecture, Building and Design
University of Melbourne

ICUC11, 29 August 2023
A methodology to determine the influence of urban form and fabric on thermal comfort, by utilising a comprehensive combination of possible urban forms, an urban morphology data source, and micro-climate modelling.

**Objectives**

- Model the full range of representative combinations of urban form (mixes of land cover and urban and vegetative structure) at a micro-scale
- Determine the importance and relative influence of each feature type on thermal performance.
- Discuss how the results can be extended to a city-wide assessment of thermal comfort such that we identify areas that may benefit from heat mitigation interventions. The proposed methodology will inform future research in planning and development of realistic strategies for urban heat mitigation.
Overall workflow

Scenario generation
9814 scenarios across the urban parameter space (Figure 2)

Micro-scale modelling
Use VTUF-3D to model 9814 scenarios (Figure 2)

Comprehensive urban form analysis
Analyse parameters impact on temperatures (Figure 6)

Temporal Analysis
Diurnal temperature variations due to parameters and feature importance (Figures 4 & 5, Table 1)

City-wide heat map construction
Heat maps based only on urban form and fabric (Figures 9 & 10)

Comparison with observations
Compare observed LST to ground level heat without geography and regional weather

Spatial Analysis
Distributions of temperatures across scenarios (Figure 8)
Development of the VTUF-3D v1.0 urban micro-climate model to support assessment of urban vegetation influences on human thermal comfort

Kerry A. Nicer, Andrew M. Coutts, Nigel J. Tapper

1 School of Earth, Atmosphere and Environment, Monash University, Clayton, Victoria 3800, Australia
2 Transport, Health, and Urban Design Hub, Faculty of Architecture, Building, and Planning, University of Melbourne, Victoria, Australia
3 Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia

**Figure 4.2:** Integration of MAESPA tree model into VTUF-3D radiation fluxes routines, in which tilled instances of MAESPA vegetation (in green) are used to calculate radiation transmission for VTUF-3D placeholder vegetation structures (in grey).

VTUF-3D, developed to support micro-climate modelling, especially including the influences of urban vegetation and water
VTUF-3D micro-climate model

Lincoln Square, Melbourne

(Nice 2016)
Creation of VTUF-3D scenarios for 9814 variations of parameters across representative ranges in Melbourne

Example scenarios from the 9814 modelled

- 49% grass, 50% trees, 0.5% roads, 0.5% building, mean building height 5.0m, mean vegetation height 15.0m
- 9% grass, 0% trees, 31% roads, 60% building, mean building height 49.8m, mean vegetation height 0m
- 9% grass, 10% trees, 71% roads, 10% building, mean building height 14.8m, mean vegetation height 0.5m.
- Modelled 3-dimensional results of UTCI for scenario (c) at 2pm February 12, 2004.
Forcing data for comparison day

- **Air temperature (°C)**
  - 01:00 to 21:00
  - Range: 16 to 26

- **Incoming shortwave (W/m²)**
  - 01:00 to 21:00
  - Range: 0 to 1000

- **Wind speed (m/s)**
  - 01:00 to 21:00
  - Range: 1 to 6

- **Water vapour pressure (mb)**
  - 01:00 to 21:00
  - Range: 1.05 to 1.25
Air temperature over surface and height ranges

Mean $T_{can}$ outcomes clustered by 10% surface fraction ranges of a) grass, b) streets, c) trees, and d) buildings and e) average vegetation and f) average building heights clustered by 0.8m increases over a diurnal cycle of February 12, 2004
Mean UTCI outcomes clustered by 10% surface fraction ranges of a) grass, b) streets, c) trees, and d) buildings and e) average vegetation and f) average building heights clustered by 0.8m increases over a diurnal cycle of February 12, 2004.
Temperature differences summary

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
<th>↑ Trees</th>
<th>↑ Grass</th>
<th>↑ Bld</th>
<th>↑ Street</th>
<th>↑ Veg Ht</th>
<th>↑ Bld Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{can}$</td>
<td>Night</td>
<td><strong>0.2</strong></td>
<td>-0.3</td>
<td><strong>0.6</strong></td>
<td>1.2</td>
<td><strong>0.2</strong></td>
<td><strong>0.5</strong></td>
</tr>
<tr>
<td>$T_{can}$</td>
<td>Day</td>
<td>-6.6</td>
<td>-4.8</td>
<td><strong>2.1</strong></td>
<td><strong>14.5</strong></td>
<td>-6.8</td>
<td>2.3</td>
</tr>
<tr>
<td>$UTCI$</td>
<td>Night</td>
<td>-5.8</td>
<td>-5.7</td>
<td><strong>3.8</strong></td>
<td><strong>3.3</strong></td>
<td>-5.6</td>
<td>4.0</td>
</tr>
<tr>
<td>$UTCI$</td>
<td>Day</td>
<td>-7.9</td>
<td>-9.6</td>
<td><strong>5.5</strong></td>
<td><strong>19.3</strong></td>
<td>-8.5</td>
<td><strong>5.5</strong></td>
</tr>
</tbody>
</table>

Maximum differences ($^\circ$C) in $T_{can}$ and $UTCI$ when increasing fractions from 10% to 90% and average vegetation and building heights to 4.4m. Bold indicates temperatures increase as fractions or heights increase.
Surface fractions percentages (trees, grass, buildings, and streets) and average heights (vegetation and building) vs. $T_{can}$ and UTCI for February 12, 2004, 2pm. Feature importance for each temperature type is indicated by the green background tinting.
Distributions of UTCI in individual scenarios

Distribution of UTCI across February 12, 2004 for scenarios a) 50% grass, 49.99% trees, 0.01% road, 0% building, average vegetation height of 4m, and average building height of 0m, b) 29% grass, 69% trees, 1% road, 1% building, average vegetation height of 0.5m, and average building height of 5m, c) 40% grass, 10% trees, 20% road, 30% building, average vegetation height of 2m, and average building height of 14m, and d) 19% grass, 20% trees, 21% road, 40% building, average vegetation height of 1m, and average building height of 9m. Red line indicates hourly median temperature. Insert shows percent fractions of surface types.
Surface fractions in Melbourne

Surface fractions of a) grass, b) trees, c) buildings, and d) streets across Melbourne.
a) $T_{can}$ and b) UTCI heatmaps on February 12, 2004 at 2pm generated by matching the closest matching parameters of surface fractions and average heights for each 100×100m location in Melbourne from 9814 modelled scenario results (in °C).
Landsat LST vs $T_{sfc}$ of Melbourne

a) Landsat 8 land surface temperature ($^\circ$C) captured 10am December 11, 2018. Local conditions of air temperature on this day were minimum and maximum of 22 and 26$^\circ$C. b) Modelled $T_{sfc}$ ($^\circ$C) on February 12, 2004 at 10am generated by matching the closest matching parameters of surface fractions and average heights for each 100$\times$100m location in Melbourne from 9814 modelled scenario results.
Surface fractions in Sydney

Surface fractions of a) grass, b) trees, c) buildings, and d) streets across Sydney.
a) $T_{can}$ and b) UTCI heatmaps on February 12, 2004 at 2pm generated by matching the closest matching parameters of surface fractions and average heights for each 100 x 100m location in Sydney from 9814 modelled scenario results (in °C).
Landsat LST vs $T_{sfc}$ of Sydney

a) Landsat 8 land surface temperature (°C) captured 10am March 11, 2019. Local conditions of air temperature on this day were minimum and maximum of 22 and 26°C. b) Modeled $T_{sfc}$ (°C) on February 12, 2004 at 10am generated by matching the closest matching parameters of surface fractions and average heights for each 100×100m location in Sydney from 9814 modelled scenario results.
Conclusions

- Street fractions the most important feature driving heat during the daytime (all the following are street level)
- Heights (shading) provide some moderate Tcan cooling and larger UTCI cooling
- Trees provide some Tcan cooling and larger UTCI cooling
- Similar trends at nighttime, but much smaller magnitude
- Method allows city-wide heat maps based on only the composition and arrangement of urban form
- LST commonly used to heat assessments but this can be complicated and misleading
- Next steps: analysis of LCZ ranges
LCZs (very early results)
Dr Kerry Nice
Transport, Health, and Urban Systems Research Lab
Faculty of Architecture, Building and Planning
University of Melbourne
https://mothlight.github.io/

@mothlight
@mothlight@fediscience.org