ANTHROPOGENIC HEAT CONTRIBUTION TO AIR TEMPERATURE INCREASE AT PEDESTRIAN HEIGHT IN SINGAPORE’S HIGH DENSITY CENTRAL BUSINESS DISTRICT (CBD)

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• INTRO (UHI & ANTHROPOGENIC HEAT)
• SITE MEASUREMENT
• PRELIMINARY STUDIES (ROADSIDE MEASUREMENT)
• PRELIMINARY STUDIES (CFD SIMULATION)
• CONCLUSION & FUTURE WORK
Representation of the possible causes of the UHI effect. (Toparlar et al., 2014)
Conceptual representation of the urban energy balance for a balancing volume that reaches from the depth where no exchange with the subsurface is found \((z_b)\) to the measurement height on a tower above the urban ecosystem \((z_t)\). (Grimmond and Christen, 2012)

\[ Q^* + Q_F = Q_H + Q_E + \Delta Q_S \]

\[ Q_F = Q_M + Q_V + Q_B \]

Flowchart of the LUCY global anthropogenic heat. (Allen et al., 2011)

Bohnenstengel et al. (2013), Chen et al. (2009); Kikegawa et al. (2014); Krpo et al. (2010); Li et al. (2014); Fan & Sailor (2005); Jusuf & Wong (2009)
Anthropogenic heat contributes 0.4 ºC - 3ºC to the air temperature.
Singapore’s diurnal and weekly variation of anthropogenic heat emissions. (Quah & Roth, 2012)
Annual energy consumption per capita versus combined total of annual heating and cooling degree days (°C) for countries with a population greater than 1 million for 2005. (Lindberg et al., 2013)
## ANTHROPOGENIC HEAT

### Cities population and vehicles density

<table>
<thead>
<tr>
<th>City</th>
<th>Tokyo</th>
<th>London</th>
<th>Guangzhou</th>
<th>Singapore</th>
<th>Hong Kong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Vehicles (per 1,000 people):</td>
<td>350 (cars)</td>
<td>317.2 (cars)</td>
<td>150</td>
<td><strong>149</strong></td>
<td><strong>77</strong></td>
</tr>
<tr>
<td>Population Density (/sqkm):</td>
<td>6,029</td>
<td>5,285</td>
<td>1,708</td>
<td><strong>7,669</strong></td>
<td><strong>6,516</strong></td>
</tr>
<tr>
<td>H/W Ratio:</td>
<td>0.4142</td>
<td>0.47</td>
<td>0.8</td>
<td><strong>2.45</strong></td>
<td>2.99 / 4.01</td>
</tr>
</tbody>
</table>

*H/W = Height to Width

Vertical obstruction angle restrictions in different cities. (Ng, 2009 & Ng, 2012)
Number of cars per 100 persons and road density (km/sqkm). (LTA, 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>245,000</td>
</tr>
<tr>
<td>2003</td>
<td>244,000</td>
</tr>
<tr>
<td>2011</td>
<td>300,000</td>
</tr>
<tr>
<td>2012</td>
<td>292,000</td>
</tr>
</tbody>
</table>

Motor vehicle population. (LTA, 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>706,956</td>
</tr>
<tr>
<td>2003</td>
<td>711,043</td>
</tr>
<tr>
<td>2011</td>
<td>956,704</td>
</tr>
<tr>
<td>2012</td>
<td>969,910</td>
</tr>
</tbody>
</table>

Average daily traffic volume entering the CBD. (LTA, 2014)

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</tr>
</tbody>
</table>

Public bus fleet/million persons. (LTA, 2014)
The URA Masterplan showing the plot ratio figures of the measurement site at the CBD above and the new Marina Bay development below. (URA, 2014)
Lamp post locations on site.
A weather station located at the high H/W Ratio part of Robinson Road on a clear, sunny day with profiles of solar radiation, air temperature and wind speed.

Onset HOBO U30-NRC weather station kit.
Weather Stations on CBD Site

- Shading, cooling effect, idling vehicles, openness.
SITE MEASUREMENT

Weather Stations on CBD Site

Traffic Light Junction

Taxi

Bus

Canyon Edge

Overhead Bridge

-Shading, cooling effect, idling vehicles, openness.
Weekdays and weekends (February 2014) air temperature at 3.5m above ground (MR_ES=Maxwell Road_Edge of Site, RR_BS=Robinson Road_Bus Stop, BTS_BBQ=Boon Tat Street_Barbeque Stalls, TAP_TC=Telok_Ayer Park_Trees Canopy, RR_HWR=Robinson Road_High Height-to-Width Ratio, CS_TJ=Cecil Street_Traffic Junction,, CS_TS=Cecil Street_Taxi Stand, MC_OB=McCallum Street_Overhead Bridge, RR_WF=Robinson Road_Water Feature, SW_CPE=Shenton Way_Car Park Entrance).
Air Temperature distribution between weekdays and weekends (Feb 8-28, 2014) of the 5 locations.

1. Maxwell Road-Edge of the Site (MR_ES)
2. Telok Ayer Park-Tree Canopy (TAR_TC)
3. Robinson Road-Bus Stop (RR_BS)
4. Robinson Road-High Height/Width-Ratio (RR_HWR)
5. Boon Tat Street-BBQ (BTS_BBQ)

The weekends for the month are 8th, 9th, 15th, 16th, 22nd and 23rd February 2014.
PRELIMINARY STUDIES (Roadside Measurements)

Roadside measurement equipment on the 1.2m high tripod.

Fluke TiR125 thermal imager.

Bus surfaces under thermal imaging.

Roadside measurement at the bus stop in the urban canyon in the afternoon.
PRELIMINARY STUDIES (Roadside Measurements)

Temperature and bus count during rush hour of a weekend

Temperature and bus count during rush hour of a weekday
PRELIMINARY STUDIES (CFD Simulation)

Computational Fluid Dynamics (CFD) Simulation

Fluent 15: Realizable K-Epsilon with buoyancy, solar load model & S2S radiation, transient

H/W 2 & 4
(8 & 16 stories)
PRELIMINARY STUDIES (CFD Simulation)

North & East Wind Directions 2m Pedestrian Height
2.3m/s @ 15m.
PRELIMINARY STUDIES (CFD Simulation)
PRELIMINARY STUDIES (CFD Simulation)

Parallel Flow (Left Elevation)  

Perpendicular Flow (Left Elevation)
PRELIMINARY STUDIES (CFD Simulation)

Without and with bus heat.

Bus Heat

- Yes
- No
PRELIMINARY STUDIES (CFD Simulation)

Density Comparison – Slab 8 stories VS. Slab 16 stories perpendicular flows

Higher density (floors) is worse in terms of heat trap & low wind speed, heat trapped by recirculating zones. Lower density (floors) enables the heat to dissipate over the shallow canyon.
PRELIMINARY STUDIES (CFD Simulation)

Density Comparison for Perpendicular Flow (Section View)

Slab 8 stories VS. Slab 16 stories
Higher density (floors) has better channeling effect (concentrated), higher wind speed, lower heat concentration
Lower density (floors) can also release heat but not as fast
PRELIMINARY STUDIES (CFD Simulation)

Density Comparison for Parallel Flow (Plan View)

Slab 8 stories VS. Slab 16 stories
Density Comparison for Parallel Flow (Section View)

Slab 8 stories VS. Slab 16 stories

PRELIMINARY STUDIES (CFD Simulation)
PRELIMINARY STUDIES (CFD Simulation)

Form Comparison – Slab 16 stories VS. Points 16 perpendicular flows
Points are better at dissipating heat and higher wind speed because of porosity
PRELIMINARY STUDIES (CFD Simulation)

Form Comparison for Perpendicular Flow (Plan View)

Points 16 stories VS. Slab 16 stories
PRELIMINARY STUDIES (CFD Simulation)

Form Comparison for Perpendicular Flow (Section View)

Points 16 stories VS. Slab 16 stories
Wind flow regulates the air temperature inside the canyon well by parallel flow. Higher H/W ratio receives better channeling effect causing higher wind speed and more shading.

Higher H/W ratio cases has higher air temperature and lower wind speed with for perpendicular flow.

If design against predominant wind direction, form permeability is more important while for design with predominant wind direction, density may help to create better urban ventilation.
Ratio for simulation
Cars : Buses : Motorcycles : Goods Vehicles
= 67 : 2 : 15 : 16
(*2 covers 2/3 of street)
View of the 100 vehicles in the canyon – towards worst case scenario.
Air temperature, wind velocity values taken at 10 spots (5 on left pedestrian, 5 on right pedestrian) in the canyon.

FUTURE WORK (CFD Simulation)
FUTURE WORK (CFD Simulation)

North Wind Flow
Highest average canyon air temperature, lowest canyon wind velocity

North East Wind Flow
Medium average canyon air temperature, lowest canyon wind velocity

East Wind Flow
Lowest average canyon air temperature, lowest canyon wind velocity
Parallel VS. Perpendicular Flow Difference (Plan)

Parallel flow has higher wind speed, lower recirculating zones
Perpendicular flow has lower wind speed, higher temperature because of recirculating zones
Parallel VS. Perpendicular Flow Difference (Section)

Parallel flow has higher wind speed, lower recirculating zones
Perpendicular flow has lower wind speed, higher temperature because of recirculating zones
**Wind direction** plays a major role in keeping the canyon air temperature low as demonstrated by the simulation, where the **parallel direction** gives the best performance (because of no obstruction).

Hence, the **porosity (especially at pedestrian height)** of the urban form will likely play a major role in determining how much heat can be transported out from the canyon.
Other urban morphologies / geometric variables will be explored together to find their correlations to urban ventilation and air temperature of pedestrian height.

Considering EUI (Energy Use Intensity) rejecting from building rooftops as well (QB).

Key density and morphology variables.
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THANK YOU!

Q & A
Fighting Urban Heat Island (UHI) and Climate Change through Mitigation and Adaptation

www.ic2uhi2016.org

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