Effect of Residential Tower Geometries on Urban Wind Environment

Ruffina Thilakaratne, Paul Chu, Yana Xiao

Chu Hai College of Higher Education
Pedestrian Ventilation Challenges in Hong Kong

• Extremely high density in urban areas has led to a number of urban thermal comfort issues: stagnant wind, air pollution concentration and urban heat island effect

• The study investigates
  • the impacts created by podium type residential developments on pedestrian level air ventilation speed
  • impact from residential tower geometries on urban wind environment
Research design

- Correlation between building typologies & pedestrian wind performance
- Correlation between design modifications to podium developments & pedestrian wind performance
- Correlation between building geometries & urban wind performance

Development of 3D digital urban models for Tsuen Wan

- Development of historic wind profiles based on air ventilation simulation platform ANSYS Fluent
  - Wind profiles: 1960 – 2015 ten year interval study
  - Wind profiles: 1997- 2015 three year interval study

Onsite measurements for simulation results verification & setting parameters

- Factory estate A
- Factory estate B
Methodology

• Establishment of cell resolution appropriate for city scale AVA study adhering to AVA guidelines
• Verifying results with on-site measurements
• Development of historical wind profiles from 1960-2015
• Correlational analysis of development trends and building typologies on pedestrian wind environment
• Testing impacts from podium & towers residential typology on pedestrian wind
• Testing the influence from voids created on the podium on wind speed
• Testing effects of tower geometries on urban wind speed
## Boundary layer conditions

<table>
<thead>
<tr>
<th>Computational Domain Size</th>
<th>FLUENT CFD Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>5H inflow buffer and 5H for lateral region</td>
<td></td>
</tr>
<tr>
<td>15H downstream region, 6H in vertical region</td>
<td></td>
</tr>
<tr>
<td>Grid Expansion Ratio</td>
<td>At most 1.3 in both horizontal and vertical direction</td>
</tr>
<tr>
<td>Prism Layers</td>
<td>4 layers of prism layers with each 0.5m</td>
</tr>
<tr>
<td>Boundary Conditions</td>
<td>Symmetric condition for two side boundaries and the ceiling</td>
</tr>
<tr>
<td></td>
<td>Wall boundary condition for the ground and buildings</td>
</tr>
<tr>
<td></td>
<td>Velocity inlet condition for inflow boundaries</td>
</tr>
<tr>
<td></td>
<td>Zero gradient condition for outlet boundary</td>
</tr>
<tr>
<td>Turbulence Model</td>
<td>Realizable $k – \varepsilon$ Model</td>
</tr>
<tr>
<td>Numerical Scheme</td>
<td>High Order Schemes</td>
</tr>
<tr>
<td>Convergence Criteria</td>
<td>Scaled Residuals dropped to below $1 \times 10^{-4}$ (Casey and Wintergerste, 2000)</td>
</tr>
</tbody>
</table>
Tsuen Wan district now and then
Tsuen Wan development profile 1960-2015
SIMULATION RESULTS
CAPTURE POINTS

200 test points for calculating weighted average; every 50m

ON-SITE MEASUREMENTS
FOR DATA VERIFICATION

On site measurements conditions
- Measured on stable wind condition in the following location
- Measured both experimental sites and representative development areas within the site
- Measured wind data on major pedestrian areas every 100m
Simulation vs. real-time data validation
1960-2015 historical wind profiles

<table>
<thead>
<tr>
<th>E</th>
<th>ENE</th>
<th>ESE</th>
<th>NE</th>
<th>S</th>
<th>SE</th>
<th>SSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960s</td>
<td><img src="1960s.png" alt="Image" /></td>
<td><img src="1960s.png" alt="Image" /></td>
<td><img src="1960s.png" alt="Image" /></td>
<td><img src="1960s.png" alt="Image" /></td>
<td><img src="1960s.png" alt="Image" /></td>
<td><img src="1960s.png" alt="Image" /></td>
</tr>
<tr>
<td>1970s</td>
<td><img src="1970s.png" alt="Image" /></td>
<td><img src="1970s.png" alt="Image" /></td>
<td><img src="1970s.png" alt="Image" /></td>
<td><img src="1970s.png" alt="Image" /></td>
<td><img src="1970s.png" alt="Image" /></td>
<td><img src="1970s.png" alt="Image" /></td>
</tr>
<tr>
<td>1980s</td>
<td><img src="1980s.png" alt="Image" /></td>
<td><img src="1980s.png" alt="Image" /></td>
<td><img src="1980s.png" alt="Image" /></td>
<td><img src="1980s.png" alt="Image" /></td>
<td><img src="1980s.png" alt="Image" /></td>
<td><img src="1980s.png" alt="Image" /></td>
</tr>
<tr>
<td>1990s</td>
<td><img src="1990s.png" alt="Image" /></td>
<td><img src="1990s.png" alt="Image" /></td>
<td><img src="1990s.png" alt="Image" /></td>
<td><img src="1990s.png" alt="Image" /></td>
<td><img src="1990s.png" alt="Image" /></td>
<td><img src="1990s.png" alt="Image" /></td>
</tr>
<tr>
<td>2000s</td>
<td><img src="2000s.png" alt="Image" /></td>
<td><img src="2000s.png" alt="Image" /></td>
<td><img src="2000s.png" alt="Image" /></td>
<td><img src="2000s.png" alt="Image" /></td>
<td><img src="2000s.png" alt="Image" /></td>
<td><img src="2000s.png" alt="Image" /></td>
</tr>
<tr>
<td>2015</td>
<td><img src="2015.png" alt="Image" /></td>
<td><img src="2015.png" alt="Image" /></td>
<td><img src="2015.png" alt="Image" /></td>
<td><img src="2015.png" alt="Image" /></td>
<td><img src="2015.png" alt="Image" /></td>
<td><img src="2015.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Development trends impact on pedestrian wind

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Un-developed area (km²)</td>
<td>1.02</td>
<td>0.73</td>
<td>0.59</td>
<td>0.17</td>
<td>0.23</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>% undeveloped land</td>
<td>51%</td>
<td>29.8%</td>
<td>22.3%</td>
<td>6.1%</td>
<td>8.2%</td>
<td>8.3%</td>
<td>8.3%</td>
</tr>
<tr>
<td></td>
<td>average wind speed</td>
<td>2.97</td>
<td>2.50</td>
<td>2.28</td>
<td>2.27</td>
<td>1.88</td>
<td>1.93</td>
<td>1.84</td>
</tr>
</tbody>
</table>

Reduction in urban porosity in Tsuen Wan city centre
decrease in urban porosity from 51% to 8.3% from 1960 to 2015

0.78sqkm
Correlation between building typologies & wind speed

Correlation between reduction in urban porosity & wind velocity

Correlation between introduction of hyper podium developments in mid 1990s & drastic reduction in wind velocity
Existing factory estates as prospective redevelopment areas
Revitalization of the factory estates

15m hyper podium & tower developments

SITE A

15m hyper podium & tower developments

SITE B
<table>
<thead>
<tr>
<th><strong>CASE 1</strong></th>
<th><strong>CASE 2</strong></th>
<th><strong>CASE 3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>existing factory sites</td>
<td>Replace the factory buildings with 15m tall podium and tower type residential buildings; plot ratio 6.5 for 2015 model</td>
<td>6m high 20% void area was introduced to the podium block in Case 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>CASE 4</strong></th>
<th><strong>CASE 5</strong></th>
<th><strong>CASE 6</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>6m high 30% void area was introduced to the podium block in Case 2</td>
<td>Individual towers with a linked podium</td>
<td>9m podium elevated 6m above ground</td>
</tr>
</tbody>
</table>
Testing with modifications to the podium
Wind profiles in the two test sites

Site A is surrounded by buildings particularly on the East, South East and North East wind directions.

Site B is relatively exposed to wind from these directions.

Site B indicated better wind levels compares to site A.

Therefore inner core of the site B was considered for assessment in order to make it comparable to site A.
Modifications to podiums & wind profiles

- Current factory estates: 1.24 m/s
- Hyper podium towers: 1.21 m/s
- 20% void in the podium: 1.24 m/s
- 30% void in the podium: 1.34 m/s
- Individual tower: 1.29 m/s
- 6m elevated podium: 1.14 m/s

Narrow building blocks and 20% void in the podium demonstrate similar improvement in wind velocity. 30% void in the podium & individual towers improve pedestrian wind velocity.
Wind behavior around different masses

Individual towers indicate better wind behavior around the masses. However, adequate spacing between buildings are important for better wind dispersion.

Bulky masses may create Venturi effect on the windward side of the podium due to wind bouncing. Nina tower podium results in stagnant wind in the surrounding.
Evolution of building typologies in Tsuen Wan from 1950s to 2015

Building Volume Comparison

Building Volumes three different building geometry in Tsuen Wan in 2015 (million m³)
Modifications to tower geometries

Four different building geometries tested for their impact on Urban Ventilation

Quasi-cruciform plan towers
Cylindrical towers
Square towers
Quasi-cruciform towers with balconies
Building geometry impact on wind speed at different height zones

Similar trends around different tower geometries
Pedestrian wind behavior around different geometries

Variation in heights demonstrated the weakest performance perhaps due to the increased roughness created by changing masses.

Towers with balconies and cruciform shaped towers demonstrated better wind performance.
Findings & conclusions

• Wind performance in the two experimental sites reports microclimatic effects influence on urban ventilation levels

• Small block sizes in the factory sites facilitate better wind performance compared with the hypothetical podium design tested

• Although marginal 30% void in the podiums & individual towers indicate improvements in the pedestrian wind levels compared to other options

• Findings from this study call for review of residential development trends and particular attention to CDA policy
Findings & conclusions

• Individual tower developments although is more desirable than podium developments, they require adequate spacing among towers

• Wind amplification could be observed around the windward side of hyper podium developments
Findings & conclusions

- Varying height of towers do not represent any significant impact on the wind environment.
- Wind behavior around different geometries demonstrated similar trends even at varying heights.
Findings & conclusions

- Cruciform towers and cruciform towers with balconies outperformed wind speed around square and cylindrical towers.
- Compliments the role of balconies as a green feature in improving urban ventilation.
- Cylindrical towers indicate the lowest wind performance due to the laminar wind flow facilitated by the smooth building envelope.
- Initial studies indicate gap between towers influence ventilation levels.
- Findings from this study provides references for designing sustainable and liveable neighborhoods.
Thank you

Acknowledgement:
The work described in this paper & presentation is fully supported by a grant from the Research Grant Council of the Hong Kong Special Administrative Regio, China Project No. UGC/IDS13/14
As a fast progressing city with unsustainable economic and physical development, Hong Kong needs to develop its resilience and resiliency to reduce urban risks and improve the ability to respond to future disasters and changes. The conference brings together experts in infrastructure, urban or disaster management to exchange valuable experiences to share the knowledge and best practices in Hong Kong. This conference aims to foment this dialogue between local & international experts.

RESILIENT & ROBUST CITIES
2nd Annual Conference hosted by
Chu Hai College of Higher Education
15th December 2017

Speakers:
MR. MICHAEL BERKOWITZ
PROF. EDWINO CHONG
PROF. ANTHONY J. MCCLELLAN

Mr. WONG KAM SING
Professor P. R. H. Suen

Speakers :
ME. JO DA SILVA

Conference Chair :
DR. BUTTINA TRINAGARANE

Organisers:

International Co-owners:

Sustainable Built Environment Conference

Supporting Organisations:

WORLD Sustainable Built Environment Conference

CONSTRUCTION INDUSTRY COUNCIL
HKGBC
SBE SERIES
CIB
iiSBE
Global Alliance for Buildings and Construction