The Role of Wind in Natural Ventilation Simulations Using Airflow Network Models

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Outline

- Natural Ventilation
- Wind and Buildings
- Design Tools
- $C_p$ Calculation Methods
- Natural Ventilation Modelling: Proposed Best Practice Approach
- Case Study
- Conclusions
Designing for Natural Ventilation

- Complex natural ventilation design
  - Fully naturally ventilated
  - Mixed ventilation
- Importance of high-end analysis
- Analysis tools
  - Airflow network models, CFD, Wind Tunnel, Expert knowledge!
Natural Ventilation Concepts
Flow Paths

Wind Driven Cross Ventilation

Single Sided Ventilation

Buoyancy Driven Stack Ventilation
Natural Ventilation: Driving Forces

- *The art* of balancing driving pressure differences and restricting pressure losses
- Two driving forces for naturally ventilated environments
  - Buoyancy due to heat gain/load: 0.3 – 3.0 Pa
  - Wind driven pressures: 1 – 35 Pa
- One typically draws air from bottom to top
- Natural ventilation tends to be transient
Wind and Buildings

Wind and Buildings
Wind and Buildings

- Flow around simple buildings in simple terrain is reasonably well understood by most.
- Separation zones produce recirculation areas with low, fluctuating pressures, that are problematic in providing driving forces.
- Wake of upstream buildings / obstructions and additional turbulence can significantly change flow behaviour.
Wind and Buildings

- For more complex building shapes, Upstream obstructions could be different parts of the same building
- These impacts are not always intuitive!
- How do we make predictions?
Complex Flows (example)
Complex Flows (example)
Natural Ventilation Design Tools

1) Airflow Network Models

- Coupled to thermal dynamic simulation tools
- Bulk airflow movement, average temperatures
- Airflow into buildings
  - At interface, assign Wind Pressure Coefficient ($C_p$) values,
  - Prediction of internal airflow due to wind is only as accurate as the assigned $C_p$ values
Natural Ventilation Design Tools

1) Airflow Network Models (cont…)

- Default $C_p$ values based on AIVC Guide to Energy Efficient Ventilation
  - based on number of wind tunnel tests for generic, low-rise buildings
  - Typically, values only apply as “acceptable initial approximations” for buildings with a shape close to rectangular that do not exceed 3 or 4 storeys in height.
Natural Ventilation Design Tools

2) Computational Fluid Dynamics (CFD)

- Used for internal and external building airflows
- Internal flow:
  - Determine localized air speeds (find stagnation zones)
  - Determine localized air temperatures (comfort)
  - Radiative heat transfer calcs (radiant heating/cooling, direct solar)
  - Detailed thermal comfort calculations
  - Increased calc time, snapshots in time
CFD Modeling (example)
$C_p$ Calculation Methods

- Several methods available, varying accuracy
  - Desktop Estimates
  - External Flow Modelling using CFD
  - Wind Tunnel Testing
- Depends on study to which values will be applied
C_p Calculation Methods

Desktop Estimates

- Based on:
  - Known C_p values from wind tunnel tests and measurements on existing buildings,
  - Shape of the proposed building,
  - Site exposure,
  - Expert’s experience
- Quick, accuracy depends on relevant data
Cp Calculation Methods

External Flow Modelling Using CFD

- 3-d computer model of building
- Environmental domain, large enough
- Boundary conditions
- Cell resolution, grid-independence, convergence
- Representation of turbulence
- All CFD modelling has trouble predicting the flow around the downstream side of a building
- Accuracy, enough to provide good qualitative information on local wind climate around naturally ventilated building,
  - Early conceptual stage
C<sub>p</sub> Calculation Methods

Wind Tunnel Testing

- Scale model testing
- Pressure taps at openings locations
- Surrounding terrain, natural & constructed obstructions
- Most effective method for predicting wind pressures acting on the natural ventilation openings of a building
Windtunnel Measurements
Transverse $C_p$ datasets
- AIVC Applications Guide
  - (3 storeys or less, square surfaces, 3 levels of site exposures)
- Hybrid prediction methods

Limitations with transferability of default values

Example: IES VE (MacroFlo)
- 66 exposure types, 16 varied angles of attack
Natural Ventilation Design: Proposed Approach

1) Outline of Analysis
   - Identify internal/external loads
   - Specify target flow and temperature conditions
   - Determine range of flow rates required to balance
   - Identify any limiting factors on design (i.e. noise, pollutants)

Figure 5.3 Acceptable operative temperature ranges for naturally conditioned spaces.
Natural Ventilation Design: Proposed Approach

2) Obtain site specific wind data
Natural Ventilation Design: Proposed Approach

3) Obtain $C_p$ Values
   - Specific wind tunnel data
   - Exterior CFD analysis
   - Expert estimate

4) Airflow Network Model
   - Yearly performance
   - Compare opening arrangements, control strategies, construction materials, etc.

5) CFD Study
   - Internal airflows
   - Complex designs
Case Study

- Lab/Research building, Eastern Canada
- Building shape deviates from 3-storey rectangular building
Case Study

- Transposed existing wind tunnel data
- Open/suburban profile (alpha=0.17)
- Blank disk (no surrounding buildings)
- Wind engineer developed estimates of $C_p$ values for opening locations
Case Study

- 24 external facade wind pressure zones based on exposure, height and orientation
- Wind tunnel data transposed
### Case Study

#### Table 1: Wind $C_p$ as Predicted by Wind Tunnel Estimations (Est) and Zonal Airflow Model (IES)

<table>
<thead>
<tr>
<th>Building Zones</th>
<th>Exposure Type</th>
<th>Wall</th>
<th>$0^\circ$ (Est)</th>
<th>$0^\circ$ (IES)</th>
<th>% DIFF</th>
<th>$90^\circ$ (Est)</th>
<th>$90^\circ$ (IES)</th>
<th>% DIFF</th>
<th>$180^\circ$ (Est)</th>
<th>$180^\circ$ (IES)</th>
<th>% DIFF</th>
<th>$270^\circ$ (Est)</th>
<th>$270^\circ$ (IES)</th>
<th>% DIFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone1</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.36</td>
<td>0.65</td>
<td>81%</td>
<td>0.68</td>
<td>0.65</td>
<td>5%</td>
<td>-0.49</td>
<td>-0.28</td>
<td>43%</td>
<td>-0.30</td>
<td>-0.65</td>
<td>115%</td>
</tr>
<tr>
<td>Zone2</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.58</td>
<td>0.65</td>
<td>12%</td>
<td>-0.56</td>
<td>-0.65</td>
<td>15%</td>
<td>-0.46</td>
<td>-0.28</td>
<td>39%</td>
<td>-0.50</td>
<td>-0.65</td>
<td>29%</td>
</tr>
<tr>
<td>Zone3</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.36</td>
<td>0.65</td>
<td>81%</td>
<td>-0.32</td>
<td>-0.65</td>
<td>102%</td>
<td>-0.49</td>
<td>-0.28</td>
<td>43%</td>
<td>-0.66</td>
<td>-0.65</td>
<td>2%</td>
</tr>
<tr>
<td>Zone4</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.50</td>
<td>0.65</td>
<td>30%</td>
<td>-0.60</td>
<td>-0.65</td>
<td>8%</td>
<td>-0.25</td>
<td>-0.28</td>
<td>12%</td>
<td>-0.63</td>
<td>-0.65</td>
<td>2%</td>
</tr>
<tr>
<td>Zone5</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.49</td>
<td>0.65</td>
<td>33%</td>
<td>-0.57</td>
<td>-0.65</td>
<td>13%</td>
<td>-0.26</td>
<td>-0.28</td>
<td>8%</td>
<td>-0.70</td>
<td>-0.65</td>
<td>8%</td>
</tr>
<tr>
<td>Zone6</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.38</td>
<td>0.65</td>
<td>71%</td>
<td>-0.66</td>
<td>-0.65</td>
<td>2%</td>
<td>-0.43</td>
<td>-0.28</td>
<td>35%</td>
<td>-0.31</td>
<td>-0.65</td>
<td>108%</td>
</tr>
<tr>
<td>Zone7</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.62</td>
<td>0.65</td>
<td>5%</td>
<td>-0.52</td>
<td>-0.65</td>
<td>24%</td>
<td>-0.40</td>
<td>-0.28</td>
<td>30%</td>
<td>-0.52</td>
<td>-0.65</td>
<td>24%</td>
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<td>Zone8</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.37</td>
<td>0.65</td>
<td>76%</td>
<td>-0.32</td>
<td>-0.65</td>
<td>102%</td>
<td>-0.43</td>
<td>-0.28</td>
<td>35%</td>
<td>-0.70</td>
<td>-0.65</td>
<td>8%</td>
</tr>
<tr>
<td>Zone9</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.53</td>
<td>0.65</td>
<td>23%</td>
<td>-0.66</td>
<td>-0.65</td>
<td>2%</td>
<td>-0.24</td>
<td>-0.28</td>
<td>17%</td>
<td>-0.55</td>
<td>-0.65</td>
<td>17%</td>
</tr>
<tr>
<td>Zone10</td>
<td>high-rise (h/H=0.8)</td>
<td>exposed</td>
<td>0.52</td>
<td>0.65</td>
<td>25%</td>
<td>-0.63</td>
<td>-0.65</td>
<td>2%</td>
<td>-0.25</td>
<td>-0.28</td>
<td>12%</td>
<td>-0.62</td>
<td>-0.65</td>
<td>4%</td>
</tr>
<tr>
<td>Zone11</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.56</td>
<td>0.39</td>
<td>31%</td>
<td>-0.65</td>
<td>-0.56</td>
<td>14%</td>
<td>-0.26</td>
<td>-0.27</td>
<td>4%</td>
<td>-0.72</td>
<td>-0.56</td>
<td>22%</td>
</tr>
<tr>
<td>Zone12</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.32</td>
<td>0.39</td>
<td>20%</td>
<td>-0.56</td>
<td>-0.56</td>
<td>0%</td>
<td>-0.26</td>
<td>-0.27</td>
<td>4%</td>
<td>-0.76</td>
<td>-0.56</td>
<td>26%</td>
</tr>
<tr>
<td>Zone13</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.33</td>
<td>0.39</td>
<td>17%</td>
<td>-0.71</td>
<td>-0.56</td>
<td>21%</td>
<td>-0.47</td>
<td>-0.27</td>
<td>43%</td>
<td>-0.26</td>
<td>-0.56</td>
<td>115%</td>
</tr>
<tr>
<td>Zone14</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.58</td>
<td>0.39</td>
<td>34%</td>
<td>-0.48</td>
<td>-0.56</td>
<td>17%</td>
<td>-0.46</td>
<td>-0.27</td>
<td>41%</td>
<td>-0.48</td>
<td>-0.56</td>
<td>17%</td>
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<td>Zone15</td>
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<td>exposed</td>
<td>0.31</td>
<td>0.39</td>
<td>24%</td>
<td>-0.27</td>
<td>-0.56</td>
<td>107%</td>
<td>-0.47</td>
<td>-0.27</td>
<td>43%</td>
<td>-0.74</td>
<td>-0.56</td>
<td>24%</td>
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<tr>
<td>Zone16</td>
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<td>exposed</td>
<td>0.48</td>
<td>0.39</td>
<td>20%</td>
<td>-0.71</td>
<td>-0.56</td>
<td>21%</td>
<td>-0.26</td>
<td>-0.27</td>
<td>4%</td>
<td>-0.64</td>
<td>-0.56</td>
<td>13%</td>
</tr>
<tr>
<td>Zone17</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.32</td>
<td>0.39</td>
<td>20%</td>
<td>-0.74</td>
<td>-0.56</td>
<td>24%</td>
<td>-0.53</td>
<td>-0.27</td>
<td>49%</td>
<td>-0.24</td>
<td>-0.56</td>
<td>133%</td>
</tr>
<tr>
<td>Zone18</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.53</td>
<td>0.39</td>
<td>27%</td>
<td>-0.51</td>
<td>-0.56</td>
<td>10%</td>
<td>-0.53</td>
<td>-0.27</td>
<td>49%</td>
<td>-0.45</td>
<td>-0.56</td>
<td>24%</td>
</tr>
<tr>
<td>Zone19</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.51</td>
<td>0.39</td>
<td>175%</td>
<td>-0.53</td>
<td>-0.56</td>
<td>6%</td>
<td>-0.45</td>
<td>-0.27</td>
<td>40%</td>
<td>0.53</td>
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<td>206%</td>
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<td>exposed</td>
<td>0.32</td>
<td>0.39</td>
<td>20%</td>
<td>-0.74</td>
<td>-0.56</td>
<td>24%</td>
<td>-0.53</td>
<td>-0.27</td>
<td>49%</td>
<td>-0.24</td>
<td>-0.56</td>
<td>133%</td>
</tr>
<tr>
<td>Zone21</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.53</td>
<td>0.39</td>
<td>27%</td>
<td>-0.51</td>
<td>-0.56</td>
<td>10%</td>
<td>-0.53</td>
<td>-0.27</td>
<td>49%</td>
<td>-0.45</td>
<td>-0.56</td>
<td>24%</td>
</tr>
<tr>
<td>Zone22</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.29</td>
<td>0.39</td>
<td>33%</td>
<td>-0.27</td>
<td>-0.56</td>
<td>107%</td>
<td>-0.55</td>
<td>-0.27</td>
<td>51%</td>
<td>-0.71</td>
<td>-0.56</td>
<td>21%</td>
</tr>
<tr>
<td>Zone23</td>
<td>high-rise (h/H=0.4)</td>
<td>exposed</td>
<td>0.31</td>
<td>0.39</td>
<td>24%</td>
<td>-0.67</td>
<td>-0.56</td>
<td>16%</td>
<td>-0.27</td>
<td>-0.27</td>
<td>0%</td>
<td>-0.61</td>
<td>-0.56</td>
<td>8%</td>
</tr>
<tr>
<td>Zone24</td>
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<td>exposed</td>
<td>0.34</td>
<td>0.39</td>
<td>13%</td>
<td>-0.61</td>
<td>-0.56</td>
<td>8%</td>
<td>-0.26</td>
<td>-0.27</td>
<td>4%</td>
<td>-0.69</td>
<td>-0.56</td>
<td>19%</td>
</tr>
</tbody>
</table>
Case Study

Avg diff = 29%

Avg diff = 28%
Above are the two standard text boxes. The bottom box should be the default. If you need the top box, copy this box, paste it where you need it and then insert new text.

Images have no style applied like shown.
Conclusions

- Best practice approach for natural ventilation analysis proposed
- Scale model testing – most accurate
- Expert estimates from existing data
- CFD modelling to enhance
- $C_p$ values can vary significantly depending on approach
- Common airflow network $C_p$ derivation techniques reasonable for cubic shaped buildings
- More complex building shapes, recommend more accurate $C_p$ prediction
Thank you.
Future Work

- Detailed study directly comparing $C_p$ prediction accuracy of:
  - Desktop approximation,
  - CFD model,
  - Wind tunnel test
  - Post construction physical testing
- Varying simulation tools
- Varying building shapes and sizes
- Effect on predictions of Natural Ventilation effectiveness and design recommendations