<table>
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<th><strong>Title</strong></th>
<th>Roughness-sublayer correction for the profiles of mean velocity and turbulence over urban areas</th>
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<tr>
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<tr>
<td><strong>Citation</strong></td>
<td>The Croucher Advanced Study Institute (ASI) Programme 2015-2016: Changing Urban Climate &amp; the Impact on Urban Thermal Environment and Urban Living, The Chinese University of Hong Kong, Hong Kong, 7-11 December 2015.</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>2015</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/235025">http://hdl.handle.net/10722/235025</a></td>
</tr>
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Background

- Monin-Obukhov similarity theory (MOST) applies in inertial sub-layer (ISL) but fails in roughness sub-layer (RSL) because the flow structure in RSL is highly inhomogeneous.
- Extrapolation of the conventional logarithmic law of wall into the RSL likely overlooks the inhomogeneity.
- Need for an analytical expression for mean velocity profile and ventilation estimate, including a new RSL correction, that is applicable over the urban boundary layer.

Analytical Expression for RSL flow correction

Assumptions:

- \( \Phi_m = \phi_u \phi_m = \phi_u \left( \frac{z}{z^*} \right) \)
  - \( z \) is the elevation & \( z^* \) the RSL height.
- The gradient of the wind profile in dimensionless form is,
  \[ \frac{du}{dz} = u^* \frac{\phi_m}{\kappa} \left( \frac{z}{z^*} \right) \]
- \( u^* \) is the wind speed, \( u^* \) the friction velocity & \( \kappa \approx 0.41 \) the von Kármán constant.

Rearrange & integrate yields,

\[ \frac{\kappa}{u_*} \ln \frac{z^*}{z} = \ln \left( \frac{z^*}{d} \right) + \int_{z}^{z^*} \frac{1}{z^*} \phi_m \, dz = \frac{d}{z^*} \]

\( d \) is the displacement height & \( z^* \) the roughness length scale.

We employ the (continuous) function of \( \phi_m \)

\[ \phi_m(z) = 1 - e^{-\mu(z/z^*)} \]

\( \mu \) is an empirical constant.

Use series expansion to calculate the exponential integral, an analytical expression for the urban RSL effects is formulated

\[ u^*(z) = \frac{1}{\kappa} \left[ \ln \left( \frac{z^*}{d} \right) - \ln \left( \frac{z}{d} \right) - \sum_{n=1}^{\infty} \frac{(-1)^n \left( \mu \frac{z}{z^*} \right)^n}{n \cdot n!} \right] \]

\( y = 0.57721 \): Euler constant.

Wind Tunnel Measurements

- The open-circuit type wind tunnel at the Department of ME, HKU was used with neutral stratification and a reference wind speed of 9 m s\(^{-1}\)
- Idealised 2D-roughness elements with different aspect ratio (AR = h/b) were used to simulate the urban areas
- Cross-wire hot-wire measurements were performed

Flows and Ventilation Estimates over Idealised Urban Areas

- Flow inhomogeneity over idealised urban areas is revealed (Fig. 3a)
- RSL & ISL are clearly identified
- The newly proposed analytical expression performs well in both RSL & ISL for the prediction of velocity profiles over a wide range of aspect ratios, 0.5 < ARs < 0.083 (Fig. 3c)
- Friction factor \( f \) & vertical velocity scale \( \tilde{w} \) are used to parameterise ventilation performance over urban areas with RSL corrections (Fig. 3b)

Next steps

- Tests with additional roughness elements of different forms using wind tunnel experiments, i.e. cube roughness, building height variability or realistic city models.
- Quantify the effect of aerodynamic roughness on RSL flows.
- Examine the RSL turbulence using mixing length models.

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