Estimating Wind Speed at an Urban Reference Height

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Step 1. Estimate \( z_r \) and \( z_0 \).

In the first step of the COST 715 procedure, the urban zero-plane displacement \( z_0 \) and the roughness sublayer height \( z_r \) are estimated from mean building height \( h \) using empirical relationships.

The determination of \( z_0 \) with the ‘rule-of-thumb’ (0.7h) delivers reasonable estimates at both BUBBLE towers. \( z_0 \) determined by different empirical relationships with morphometric data from a digital building model as well as the neutral linear wind profile result both in typical values for \( z_0 \) between 0.7 and 0.8h. \( z_r \), is a more problematic input parameter. Various experiments demonstrated, that local Reynolds stress \( u^* \) changes with \( \log h \) and shows a maximum between 1.5 and 2h. In the COST 715 procedure, \( z_r \) is interpreted as the height, where maximum local Reynolds stress is observed, rather than the height where the spatial inhomogeneities vanish. The height of the maximum \( u^* \) is surprisingly constant around 1.6h for different flow situations at both urban towers.

Step 2. Calculate the profile of local \( u^* \).

The following parameterization for the vertical profile of local \( u^* \) has been proposed by Rotach (2001), where \( a \) and \( b \) are empirical constants:

\[
\frac{u^*}{\bar{u}} = \left( \frac{z}{z_0} \right)^a \quad \text{for} \quad z > z_0
\]

\[
\frac{u^*}{\bar{u}} = \left( \frac{z}{z_r} \right)^b \quad \text{for} \quad z < z_r
\]

The parameterization suggests to interpret any measured \( u^* \) above \( z_0 \), as \( u^* \) measured close to 1.6h.

No urban \( u^* \), measured?

If Reynolds stress \( u^* \) is not measured directly in the city, the parameterization of Hanna and Chang (1992) may be applied or measurements from a rural site can be used to estimate \( u^* \) according to Bottema (1996), where \( u^* \) is an empirical factor.

\[ u^* = a \frac{u}{z_0} \]

In order to test this scenario, data from the rural site ‘Village Neuf’ which is located 4 km North of the city in an ideal area with agricultural land use is taken as input.

Figure 3 shows flow situations, when the rural site is in the upwind direction of the city. In this case, applying the parameterization leads to a systematic underestimation of the urban \( u^* \). The underestimation is remarkably stronger in periods when the rural site lies downwind of the city. This suggests, that besides local effects at the urban site, the procedure gives only reasonable results, when the wind flow at the rural site is undisturbed by the city.

Step 3. Numerically integrate the wind profile.

The wind at reference height is calculated by numerically integrating the logarithmic wind profile equation. For each integration step, the local Reynolds stress from step 2 is taken. \( u^* \) is calculated with local Obukhov length, and sensible heat flux is assumed to be constant with height.

Table 2: Comparison between modeled wind speed at a ‘reference height’ \( u_r \) over Urban Areas and (mean) measured \( u_r \) for different input configurations in terms of the slope of a linear regression \( u_r = u_r + a \cdot \text{RMS} \).

<table>
<thead>
<tr>
<th>Input wind speed</th>
<th>Rural input ( u_r )</th>
<th>Rural input ( a )</th>
<th>RMS ( a )</th>
<th>RMS ( u )</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 m/s</td>
<td>1.08</td>
<td>0.73</td>
<td>0.20</td>
<td>0.90</td>
</tr>
<tr>
<td>24 m/s</td>
<td>1.03</td>
<td>0.73</td>
<td>0.20</td>
<td>0.89</td>
</tr>
<tr>
<td>26 m/s</td>
<td>0.95</td>
<td>0.72</td>
<td>0.19</td>
<td>0.87</td>
</tr>
<tr>
<td>28 m/s</td>
<td>0.97</td>
<td>0.71</td>
<td>0.18</td>
<td>0.86</td>
</tr>
<tr>
<td>30 m/s</td>
<td>0.97</td>
<td>0.72</td>
<td>0.19</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Conclusions.

Overall, the results of the procedure are encouraging, and most configurations result in reasonable estimates of the wind speed at the reference height. However, input data from street canyon below should be avoided. The performance of the procedure is strongly dependent on how representative the input wind measurements \( u^* \) are in the horizontal average. Larger errors are associated with rural measurements and flow directions that have strong inhomogeneities and a highly variable building height.

References.

Extremer (1995). ‘Windschreiber, Rohrströmungen Parameter für Heterogene Bauflächen’, document Sekt.PfB, Lab. de Météorologie des Écoles, Centre Électro de France, Hanno M (1995), where \( \text{RMS} \) is in many cases strongly underestimated, when an overall wind direction along the canyon axis is observed. The associated flow channeling within the street canyon increases local wind speed and \( u_h \) close to the roofs and in the upper canyon part relatively to the horizontal average. As a consequence the resulting reference wind speed is overestimated when integrating upwards.

The calculations with rural \( u^* \), values (see box left) result in higher scatter between the modeled and in-situ measurements. The modeled urban \( u_r \) are in many cases strongly underestimated, which in consequence lowers the local gradients \( \text{RMS} \). Calculations with numerical integration downwards result in a strong overestimation and the ones with an upward integration show an underestimation.