THE RESISTANCE NETWORK FOR TRANSFER FROM STREET CANYONS

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1. INTRODUCTION

Models of the energy balance of the urban landscape need to account for radiative and turbulent transfer to and from all active surfaces. Whilst the radiative transfer is reasonably well understood, little is known about the turbulent transfer. On the scale of a street, turbulent transport can be represented by a network of resistances between the surfaces and the air (e.g. Masson, 2000). The values of these resistances for an urban geometry are not currently known. This paper describes how the naphthalene sublimation technique, developed in Barlow and Belcher (2002), can be used to measure these resistances in a wind tunnel model.

2. RESISTANCE NETWORK

Figure 1 shows the resistance network for a street. R_s is the street resistance, R_w(lee) and R_w(wind) the resistances for the lee and windward walls respectively; R_t is the resistance to transport out of the street canyon and R_{roof} the resistance from the building roofs.

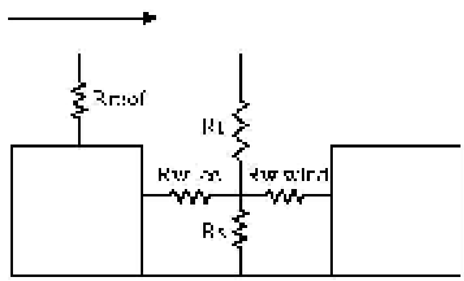

Figure 1: Resistance network for a street canyon. The arrow shows the wind direction.

The resistance, R_1, to transport from the street into the atmosphere above is given by:

$$R_1 = R_S + R_T \,. \tag{1}$$

The resistance, R_2, from the wall to the atmosphere is

$$R_2 = (W/H)R_W + R_T \,. \tag{2}$$

The resistance, R_3, from both wall and street is

$$R_3 = R_T + \frac{WR_W R_S}{WR_W + HR_S} \,. \tag{3}$$

Equations (1), (2) and (3) can then be inverted to obtain R_S, R_T and R_W in terms of R_1, R_2 and R_3.

R_1, R_2 and R_3, were measured using naphthalene sublimation. The active surface was coated with naphthalene and then the windtunnel was run at a constant windspeed. The change in mass of naphthalene over the run was then measured to give the flux out of the canyon, F. By monitoring the temperature, T, of the active surface and applying the ideal gas law, the source concentration of naphthalene vapour, ρ_S, was calculated. Combining the two gives the resistance

$$R = \frac{\rho_S}{F} \tag{4}$$

assuming that the background concentration of naphthalene is negligible. By coating (i) the street only (ii) the wall only and (iii) the street and wall with naphthalene we obtained R_1, R_2 and R_3 respectively.

3. NAPHTHALENE SUBLIMATION METHOD

Figure 2 shows a side-view of the experimental arrangement. A boundary layer was generated using a fence and roughness elements (cf. experiment B in Barlow and Belcher, 2002). An array of 8 street canyons was used with buildings of height h=12.5mm and varying street width (w=50, 12.5, 6.25mm). Naphthalene measurements were made in the eighth canyon downstream. Windspeed was measured at the top of the boundary layer at the midpoint of the eighth canyon using a Pitot-static tube. The temperatures of the street and walls were measured using thermistors.

For each geometry the resistance R_3 was determined for 5 windspeeds between $4ms^{-1}$ and $13ms^{-1}$. It was found that R_1 and R_2 could be derived from the R_3 measurements, i.e. that the measured resistances were independent of the concentration of naphthalene in the canyon. For each aspect ratio, the R_3 experiment was repeated for the both lee and windward walls.

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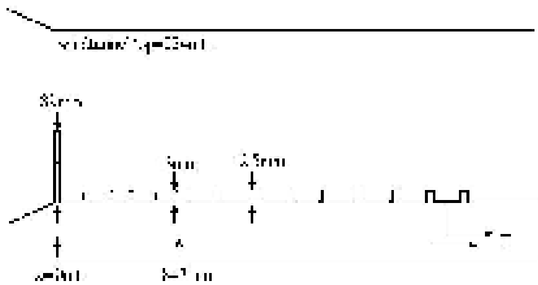

Figure 2: side-view of experimental arrangement. Temperatures of the wall and the street were measured using thermistors.

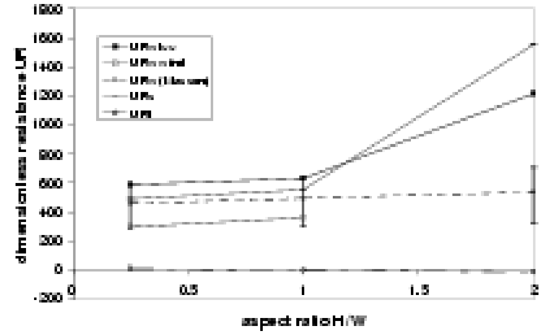

Figure 3: Dimensionless resistance UR as a function of aspect ratio H/W.

4. RESULTS

It was observed in all cases that the transfer velocity $w_T = 1/R$ was a linear function of wind speed with negligible offset, hence the dimensionless resistance $UR = U/w_T$ was constant over the range of wind speeds studied for each surface for each geometry. This suggests that the turbulence was the dominant process in transferring scalars from all surfaces. Figure 3 shows dimensionless resistance UR for each surface as a function of street aspect ratio H/W.

It can be seen that UR_w for transfer from the leeward wall is almost twice the value from the windward wall. This is consistent with measurements of tracer concentrations within a street canyon (Kastner-Klein and Plate, 1999) which showed increased concentrations of tracer at the lee wall, suggesting weaker transport in its vicinity. The dimensionless resistance for the street UR_s lies between the two values. It is interesting to compare our measured values of UR_w with values calculated using the empirical formula quoted in Masson (2000). In contrast to our measurements UR_w varies with wind speed, and a range of values is shown for each aspect ratio in figure 3. For H/W=0.25 and 1 the range of computed values of UR_w is comparable with the measured values for lee and windward walls. There are important differences for H/W=2.

UR_T is small, which suggests that once transfer from the surfaces within the canyon has occurred, ventilation from the canyon is rapid. Evidentially the shear layer at the top of the canyon air space promotes vigorous mixing with the boundary layer as suggested by the observations of Louka, Belcher & Harrison (1999).

It can be seen that there is a small increase in all values of dimensionless resistance between H/W=0.25 and 1, but a notable increase for H/W=2 for the street and leeward wall. As H/W=0.65 marks the onset of the skimming regime, this result suggests a more drastic reduction in the canyon winds for 1<H/W<2, resulting in much reduced transport from each surface within the canyon. This is consistent with the modelling results of Sini et al (1996), who observed the onset of two counter rotating vortices within the canyon for aspect ratios of H/W≥1.6. Further experiments will be carried out to clarify this point.

5. CONCLUSIONS

Naphthalene sublimation has been used to calculate resistances to turbulent transfer from surfaces within a street canyon. Results suggest that scalar transfer is largest from the windward wall and is smaller for the street surface and leeward walls. This is consistent with the decrease in wind speed around the main, intermittent canyon vortex. Transfer out of the top of the canyon is much more efficient by comparison.

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