DEPENDENCE OF STREET CANYON CONCENTRATIONS ON ABOVE ROOF WIND SPEED - IMPLICATIONS FOR NUMERICAL MODELLING

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ABSTRACT

In micro-scale numerical modelling of street canyon pollution, an inverse proportionality of additional concentration (C) with wind speed (U_roof) is often assumed for cases without buoyancy, stability effects, solar radiation and traffic induced turbulence. Detailed data analyses of two comprehensive field datasets from Göttinger Straße in Hannover and Jagtvej, Copenhagen including concentration and wind field measurements in the street and above the roof are presented. A significant deviation from the 1/U_roof dependence up to wind speeds U_roof = 8 .. 10 m/s was observed. The dependence on wind speed, amount of traffic and wind direction could be demonstrated. The most likely interpretation of this effect is, that an additional turbulence is created by traffic. A correct modelling of the influence of traffic induced turbulence is crucial for the situations in which the highest concentrations are observed; as these are cases with low wind speeds and high traffic density.

KEYWORDS:
air pollution modelling, field measurements, street pollution models, traffic induced turbulence, traffic pollution

INTRODUCTION

In micro-scale numerical modelling of street canyon pollution, an inverse proportionality of additional concentration (C) with wind speed (U_roof) is often assumed for cases without buoyancy, stability effects, solar radiation and traffic induced turbulence (e.g. Schädler et al., 1996). Normalisation of concentrations by the specific emission per length Q_L, results in these cases in the relationship :

$$C / Q_L \sim U\_roof^{-m} \quad \text{, with m=1.} \qquad (1)$$

This relationship follows from the assumption, that the wind field and the concentration distribution is scaleable with 1/U due to the high Reynolds numbers achieved for field conditions. Wind tunnel measurements with sufficiently high Reynolds numbers prove this relation (Liedke et al., 1998).

But it is often observed in field measurements that the concentrations are not inversely proportional to wind speed and the relationship depends on wind direction as well, see for example (Schädler et al., 1996) and results in this work.

For regulatory purposes applied models have to take into account that C is not inversely proportional with U_roof. Estimation of traffic induced turbulence seems to play a crucial role. But open questions are: Is traffic induced turbulence a proved explanation for the observed exponents m<1? What is the dependence of the traffic generated turbulence on the ambient wind speed and direction?

In this paper two field datasets will be analysed to elucidate these questions using concentration and turbulence measurements for different traffic conditions and wind directions. Findings from this study might be used to improve calculations with regulatory models, as e.g. MISKAM (see e.g. Guideline VDI 3782-8, 1998) , which does not take the traffic induced turbulence directly into account.

DATASETS

A very comprehensive field data set was obtained from measurements in Göttinger Straße in Hannover. The State Environmental Agency of Lower Saxony operates a permanent monitoring station in this four-lane street canyon with a traffic load of ca. 30000 vehicles/day (NLÖ, 1993). The width of the canyon is 25 m and buildings on both sides of the street are ca. 20 m high. A second field dataset from Jagtvej in Copenhagen is from a permanent pollution monitoring station operated in the frame of the Danish National Urban Monitoring Programme (NERI, 1998). Jagtvej is a busy street with about 22000 vehicles/day and is flanked on both sides with buildings about 25 m apart and about 18 m high.

In addition to street and background concentrations and meteorological data from a 10 meter mast on top of a nearby building also traffic counts are available for both field measurements. For Göttinger Straße continuous traffic counts are performed while for Jagtvej only traffic counts for a period in 94/95 exist. For Göttinger Straße continuous wind and turbulence measurements at 10 m height inside the street canyon are available too. The data from Göttinger Straße are given as half hourly values, while for Jagtvej they are on hourly basis.

RESULTS AND DISCUSSION

Göttinger Straße - normalised concentrations

The measured NOx concentrations were normalised with emissions calculated from the traffic data using: $C / Q_L = (C_{street} - C_{background}) / (NN_{truck} \bullet E_{truck} + NN_{pas} \bullet E_{pas} + NN_i \bullet E_i + \ldots)$ (2)

where NN_i is the number of vehicles of a certain class per hour and E_i is the emission factor for this class in mgNOx/(veh.•m). The normalised concentrations are plotted in a log-log diagram against the measured wind speed above roof. A line with slope of -1 indicates the ideal behaviour with m=1 from (1). In order to show the influence of traffic conditions, the data were divided in several classes according to the values given in Tables 1 and 2.

Name	number of trucks per hour	number of total traffic per hour
G1	400 .. 600	1600 .. 2200
G2	180 .. 400	1700 .. 2100
G3	100 .. 180	1100 .. 1700
G4	50 .. 100	600 .. 1300
G5	50 .. 100	200 .. 400

Table 1. Definition of traffic classes for data from Göttinger Straße.

Name	hours	number of trucks and buses p. h.	number of total traffic p. h.
J1	8 .. 15	82 .. 105	1520 .. 1750
J2	16 .. 19	31 .. 63	850 .. 1850
J3	20 .. 23	15 .. 25	840 .. 1150
J4	1 .. 6	2 .. 23	80 ..300

Table 2. Definition of traffic classes for data from Jagtvej.

For Göttinger Straße the continuous traffic counts were used for selection while for Jagtvej classes according to the hours were selected. The hours correspond to traffic conditions given by the average traffic profile. Only workingdays were used for Jagtvej.

Fig 1 shows the results obtained with data from Göttinger Straße for 1994. Only wind directions 240° to 270° are selected, which corresponds to situations when the measuring point is on the leeward side of the canyon; 263° is exactly perpendicular.

One might be disturbed by the large scatter in the plot. Several failed attempts to reduce the scatter by introducing more conditions or parameter lead us to the conclusion that this scatter originates both in the intrinsic stochastic uncertainty of the half hourly measurements and of course in the measuring errors for concentration and meteorology as well as in the uncertainty in determination of emissions. Changing the ratio of emissions between trucks and passenger cars, narrowing wind direction gap or the ranges in the traffic conditions as well as selections in respect to month and hour did not lead to a reduction in the scatter.

In spite of the huge scatter in Fig 1 a separation into different branches corresponding to the traffic classes appears for lower wind speeds. The picture becomes more clear if the classes are plotted in separate diagrams as it was done in Figs 2 and 3 for respectively classes G1 and G4.

We dare to interpret the pictures in the following way:
1) for the highest wind speeds C/Q_L is nearly the same for all traffic classes
2) for the highest class G1 the slope $m \cong 0.3$ up to the highest wind speeds (here 10 m/s)
3) for less traffic $m \cong 1$ is found for wind speeds U_roof > 3 .. 7 m/s and m<<1 for lower a U_roof
4) the wind speed for transition between these regimes depends on the traffic conditions.

Fig 4 shows the same kind of diagrams as Fig 1 for the windward situation and Fig 5 for wind directions close to parallel to the street from South East. Again a separation in the points for lower wind speeds according to the traffic classes can be found. The slope m is a function of traffic and wind speed. Comparing Figs 1, 4 and 5 it is obvious, that the concentration levels for wind speeds higher than 2 m/s are essentially depending on wind direction, but for wind speeds around 1 m/s we observe practically the same levels. Thus the wind direction plays a minor roll for lower wind speeds and the traffic induced turbulence becomes more important.

In Fig 4 the slope m seems to be even higher than 1, due to the transition from a very low concentration level for higher wind speeds (windward conditions) to a level with high concentrations for lower wind speeds, which is independent on wind directions.

Göttinger Straße - wind turbulence inside the canyon

The standard deviation σ_w of the vertical wind velocity component measured at 10 m height inside the canyon is plotted in Fig 6 against the wind speed above the roof. A clear separation in the points depending on traffic conditions is found again for lower wind speeds; less traffic influence for wind speeds higher than 6 m/s. For wind speeds between 1..3 m/s the measured σ_w is higher for situations with more traffic than for less traffic. The most likely interpretation of this effect is that an additional turbulence created by traffic is observed.

Looking at σ_w one avoids all difficulties with uncertainties in concentration measurements and estimation of emissions.

However, the contribution from thermally (convective) induced turbulence can not be excluded. Due to similar diurnal variation of traffic and solar radiation it is difficult to distinguish between these two effects. In the case of the convective contribution, one can also expect that the effect is increasing with height and thereby the influence on dispersion of pollution at the pedestrian level might not be so significant.

Jagtvej - normalised concentrations

Fig 7 shows the C/Q_L - U_roof - dependence for the leeward situation in Jagtvej, ± 60° around the exact perpendicular direction 120°. We find also for this field dataset a similar behaviour as described for Göttinger Straße. Unfortunately the relative frequency of lower wind speeds is much smaller in Copenhagen. Thus the number of observations is small in the interesting range.

For Jagtvej the share of heavy traffic is much smaller; only ca. 3%, in comparison to Göttinger Straße with 16%. Therefore the highest traffic class J1 in Jagtvej corresponds to classes G3 / G4 of Göttinger Straße. According to the interpretation in terms of traffic induced turbulence the deviation from the 1/U dependence is therefore less pronounced in Jagtvej.

CONCLUSIONS

Analyses of two field datasets reveal the big influence of traffic induced turbulence on measured street concentration. The dependence on wind speed, amount of traffic and wind direction could be demonstrated. A correct modelling of the influence of traffic induced turbulence is crucial for the situations in which the highest concentrations are observed; as these are cases with low wind speeds and high traffic density. Both the average concentrations and especially the high percentiles are strongly effected by traffic induced turbulence. The higher percentiles got recently more importance in connection with the new EU air quality directives.

Simpler methods as e. g. suggested in the Draft of the German guideline VDI 3782 (1998) that disregard the dependence on wind direction and traffic might be improved in the future. As open questions remain: How important is traffic induced turbulence for streets with other geometry, as cases with only buildings on one side of the street or even less buildings. Up to what distance from the source is this additional turbulence important? The study by Schädler et al. (1999) seems to indicate that it is only important for short distances.

ACKNOWLEDGEMENT

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FIGURES

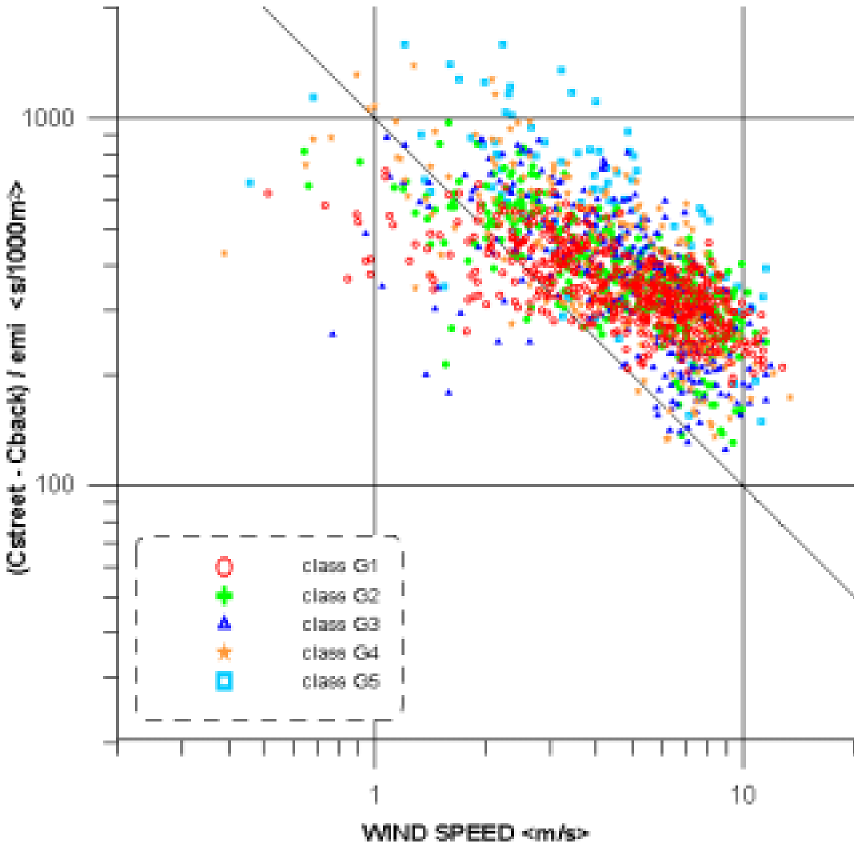

Fig 1. Normalised measured NOx concentration over wind speed for Göttinger Str. 1994. Wind direction 240°..270° (lee situation).

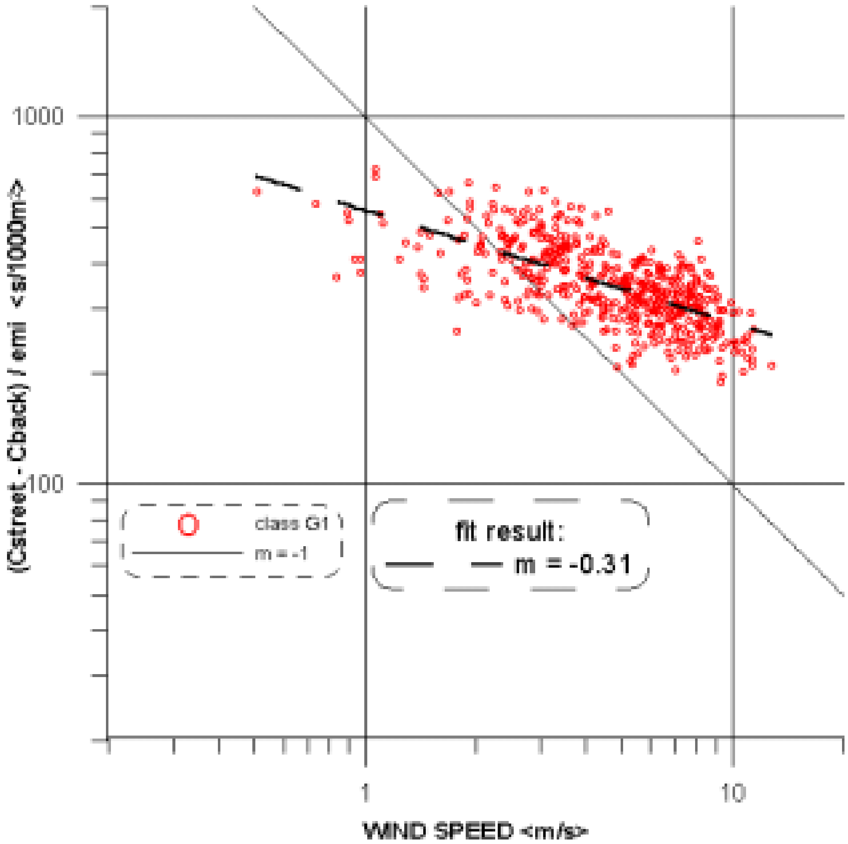

Fig 2. Normalised measured NOx concentration over wind speed for Göttinger Str. (lee situation). As Fig 1, but only class G1 and for years 1994 and 1995. The dashed line indicates a fit result.

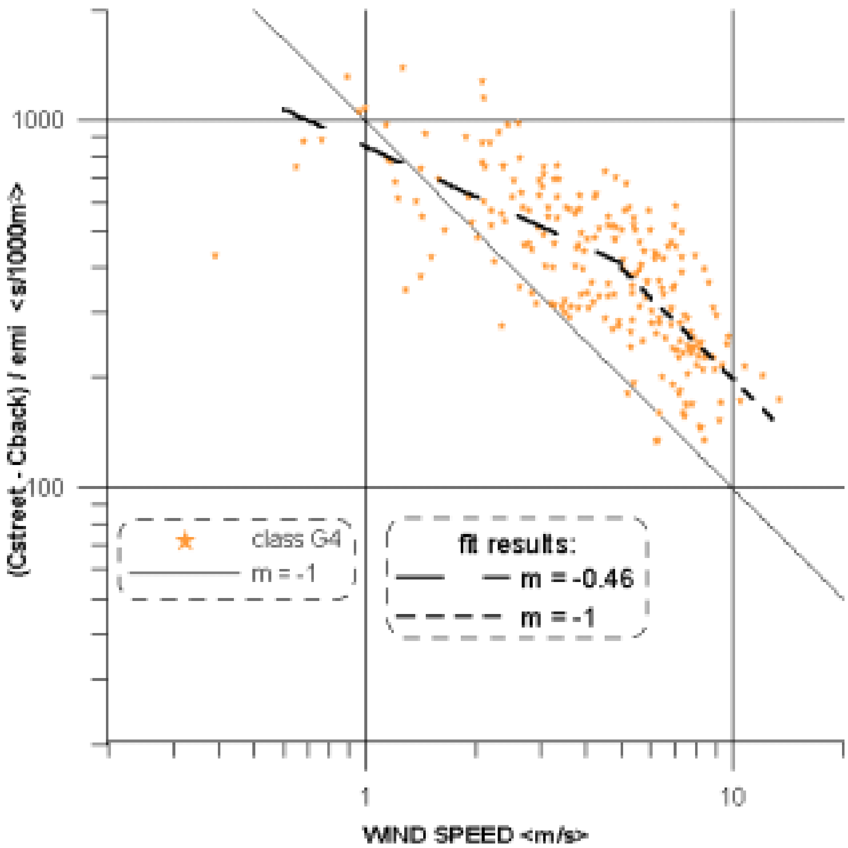

Fig 3. Normalised measured NOx concentration over wind speed for Göttinger Str. (lee situation). As Fig 1, but only class G4 and for years 1994 and 1995. The dashed lines indicate fit results for two ranges of wind speeds.

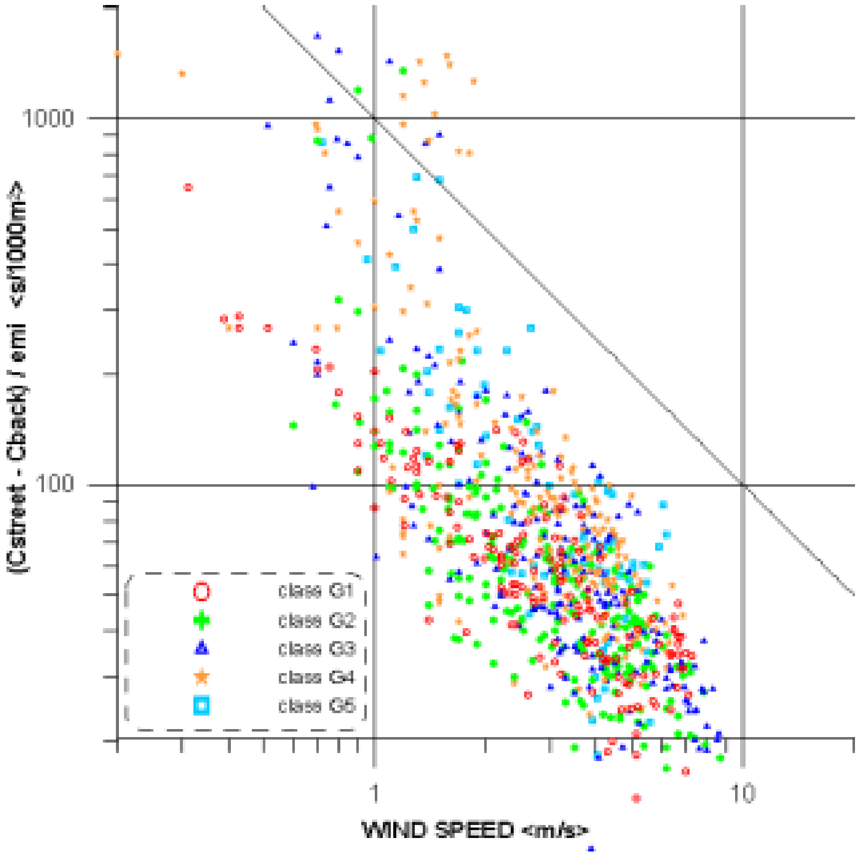

Fig 4. Normalised measured NOx concentration over wind speed for Göttinger Str. 1994 and 1995. Wind direction 40°..90° (windward situation).

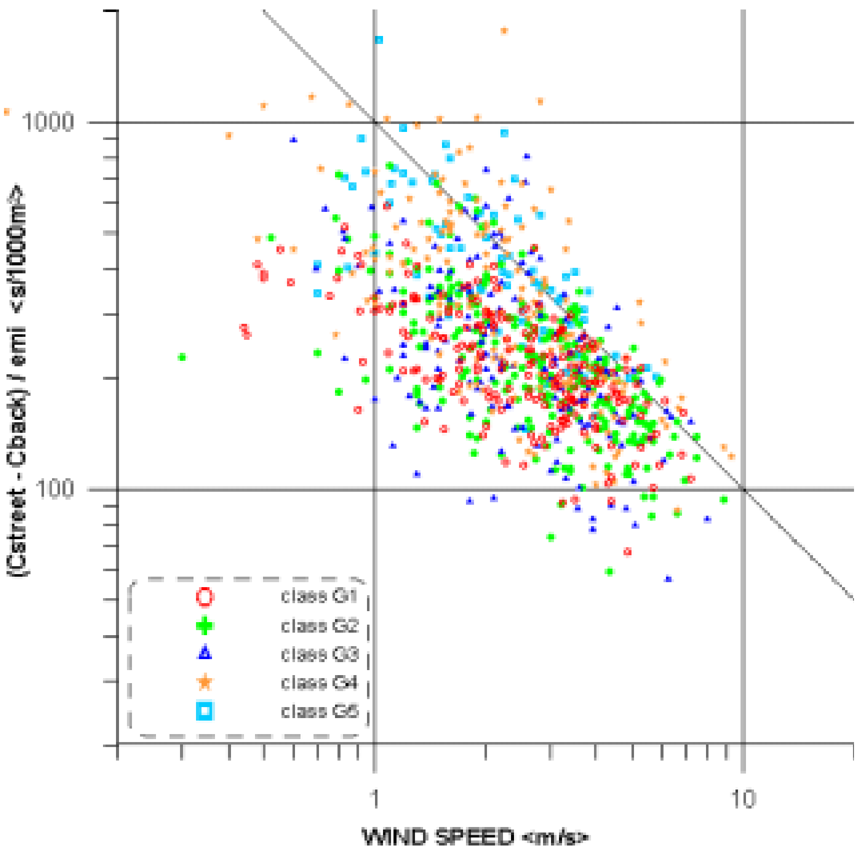

Fig 5. Normalised measured NOx concentration over wind speed for Göttinger Str. 1994 and 1995. Wind direction 145°..165° (wind parallel to the street).

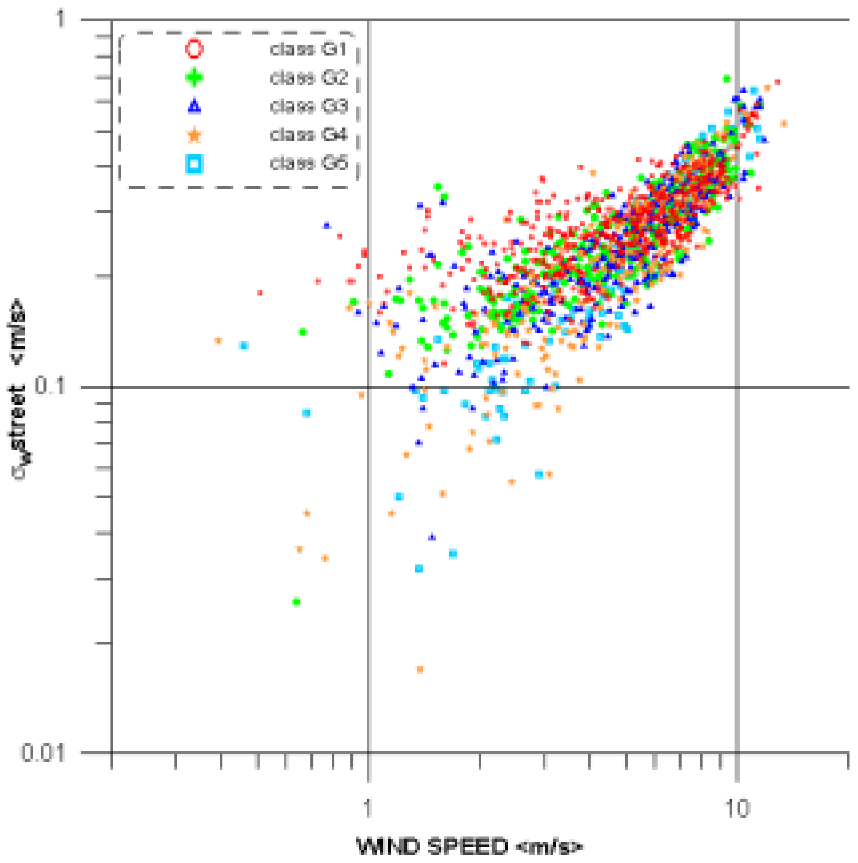

Fig 6. Measured σ_w inside the street canyon over wind speed at roof station for Göttinger Str. 1994. Wind direction 240°..270° (lee situation).

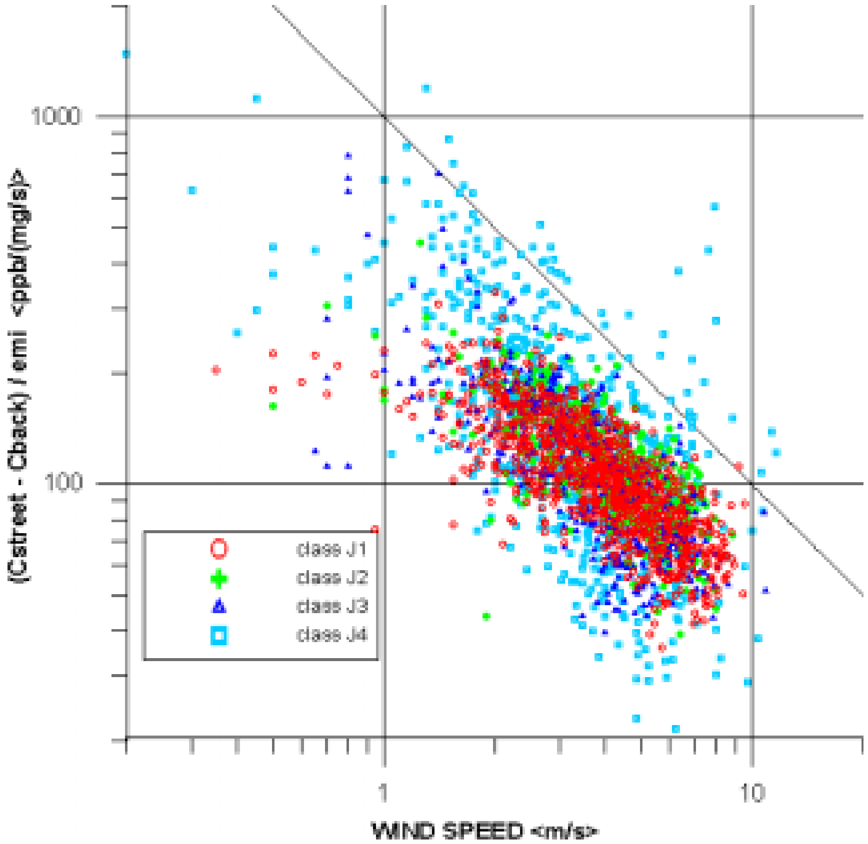

Fig 7. Normalised measured NOx concentration over wind speed for Jagtvej 1994 and 1995. Wind direction 60°..180° (lee situation).