Particulate emissions from road traffic under varying driving conditions

Fenjuan Wang,[1,2] Andreas Massling[2], Matthias Ketzel[2], Peter Wåhlin[2], Thomas Ellermann[2], Steen Solvang Jensen[2]

[1] *Institute of Nuclear and New Energy Technology, Tsinghua University, 100084, Beijing, China*

[2] *Department of Atmospheric Environment, National Environmental Research Institute, Aarhus University, 4000 Roskilde, Denmark*

Keywords: highway and urban traffic, vehicle emission factors, particle number size distribution, NO_x

INTRODUCTION

The traffic density on Danish roads has increased significantly in the last decade. Emission factors of particulate matter from road traffic are still very uncertain especially for the size-resolved number size distribution of particles. With respect to adverse health effects, the ultrafine particles including primary emitted particles and especially the soot fraction have become more attention (Sioutas et al., 2005) and future regulations will control not only the mass but also the number of emitted particles. For this reason, two field studies were conducted to study NO_x, particle mass and size-resolved submicrometer particle emission factors from road traffic under varying traffic conditions.

METHODS

One study was performed in the urban area of Copenhagen near to a major road (mean vehicle speed 50 km/h) and a second study was carried out next to a busy highway (mean vehicle speed 100 km/h) in a distance of about 30 km east of Copenhagen. Both sites were equipped with a kerbside and a background station. The following parameters were simultaneously measured at these four stations:, NO_x (NO, NO_2), $PM_{2.5}$, PM_{10} particle number size distribution (10 – 700 nm), meteorological parameters and traffic density. The traffic contribution was calculated as the difference ($\Delta C_i(t)$) between kerbside and background measurements under careful consideration of the prevailing wind directions. The traveling based emission factors (EF) (per vehicle km^{-1}) for pollutant of species i (EFP_i) was then determined based on the traffic contribution by equation 1. The dilution rate $D(t)$ ($m^2\ s^{-1}$) was calculated by the application of a dispersion model using NO_x as tracer (Kezel et al., 2003). The EFs for light duty vehicle (LDV) and heavy duty vehicle (HDV) were then determined by multiple linear regression by equation 2. N_{total}, n_{LDV} and n_{HDV} are the numbers of total vehicles, LDVs, HDVs and ε_i is the residual.

$$EFP_i = \frac{\Delta C_i(t) D(t)}{N_{total}(t)} \qquad (1)$$

$$N_{total}(t) \bullet EFP_i = n_{LDV}(t) \bullet EFP_{i(LDV)} + n_{HDV}(t) \bullet EFP_{i(HDV)} + \varepsilon_i \qquad (2)$$

RESULTS

Emission factors of NO_x, particle number and volume for the mixed fleet, HDV and LDV for both sites are list in Table 1. EFs of NO_x are found as 1.41 and 0.94 g km^{-1} at the highway and at the urban site, respectively. Corresponding values of total particle number are 215.41 10^{12} and 187.12 10^{12} km^{-1} and of particle volume are 0.03 and 0.09 $cm^3\ km^{-1}$ for the highway and the urban site, respectively, which are in good agreement of other studies (Klose et al., 2009). The ratio of particle number EF to NOx EF is 150~210 10^{12} part. g^{-1}, in the same magnitude at both sites. But the ratio of particle volume EF to NOx EF is 5 times higher at the urban site compared to the highway site. The particle number and volume size distribution emitted from traffic shows a distinct nuclei mode (~10 nm) at the highway, which is less prominent at the urban site (Fig.1) . At both sites we observed similar modes in the number distribution at ~30 nm and ~80 nm and ~200 nm in the volume distribution. These profiles could further be used for aerosol transportation modes simulating particle number emissions.

HDV are found to emit about 20 times more particles than LDV. Calculated emission factors of NO_x, total particle number and particle volume show a clear diurnal pattern during working days at both sites characterized by three maxima with decreasing peak values over daytime (4:00, 12:00, and 20:00). This pattern correlates well with the HDV share implying that these vehicles are characterized by higher emission factors of atmospheric pollutants.

The emission factor of particle number size distribution for particles smaller than 100 nm in diameter is found to be distinctly decreased compared to our previous study in 2001(Ketzel et al., 2003) at the same urban site. This is most likely due to the transition to sulphur-free (<10 ppm) diesel fuel and petrol fuel in Denmark in the beginning of 2005. By this transition, the traffic generated ultrafine particles were significantly decreased, as shown by Wåhlin (2009).

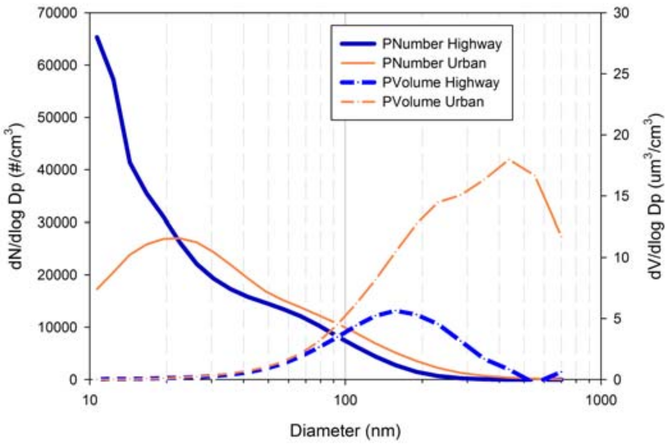

Fig. 1 Particle number (left axis) and particle volume (right axis) size distribution of traffic contribution at the urban and the highway site.

Table 1 Calculated emission factors for various pollutants given as average and splitted into LDV and HDV

	Highway site			Urban site		
Pollutant	EF (total)	EF(LDV)	EF(HDV)	EF (total)	EF(LDV)	EF(HDV)
Nox (g km^{-1})	1.4±0.03	0.7 ±0.03	9.8 ±0.29	0.9±0.02	0.5±0.03	11.9±0.59
PNumber (10^12 part.km^{-1})	215.4 ±5.3	80.8 ±6.9	1749.7 ± 67.6	187.1 ±3.1	100.5 ±6.2	2206.4±128.2
Pvolume (10^12 cm^3 km^{-1})	0.03±0.001	0.01±0.001	0.25±0.01	0.09±0.001	0.05±0.003	0.95 ±0.055
PNumber/NOx	154	115	179	208	201	185
PVolume/NOx	0.02	0.014	0.025	0.1	0.1	0.08

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NERI

[1] Department of Atmospheric Environment, National Environmental Research Institute, Aarhus University, Roskilde, Denmark
[2] Institute of Nuclear and New Energy Technology, Tsinghua University, China

Overview

- Objectives of particle emission study (a highway and an urban street in Copenhagen)
  - Address Particulate traffic emission factors in real enviroment
  - Compare emission factors under different traffic condition
  - Investigate traffic particle number emission profile for aerosol trasport modelling
- Field emission study design
- Results
  - Mesurement results
  - Estimated emission factors
- Summary

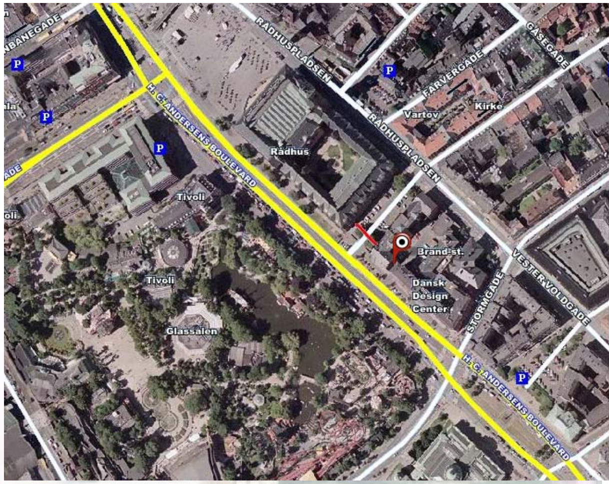
Field Design

Highway site (30 km west of Copenhagen)

- kerbside station
- background station

Urban site (Copenhagen downtown)

- kerbside station (H.C.A. Boulevard Copenhagen)
- background station (H.C. Ørsted Institute)

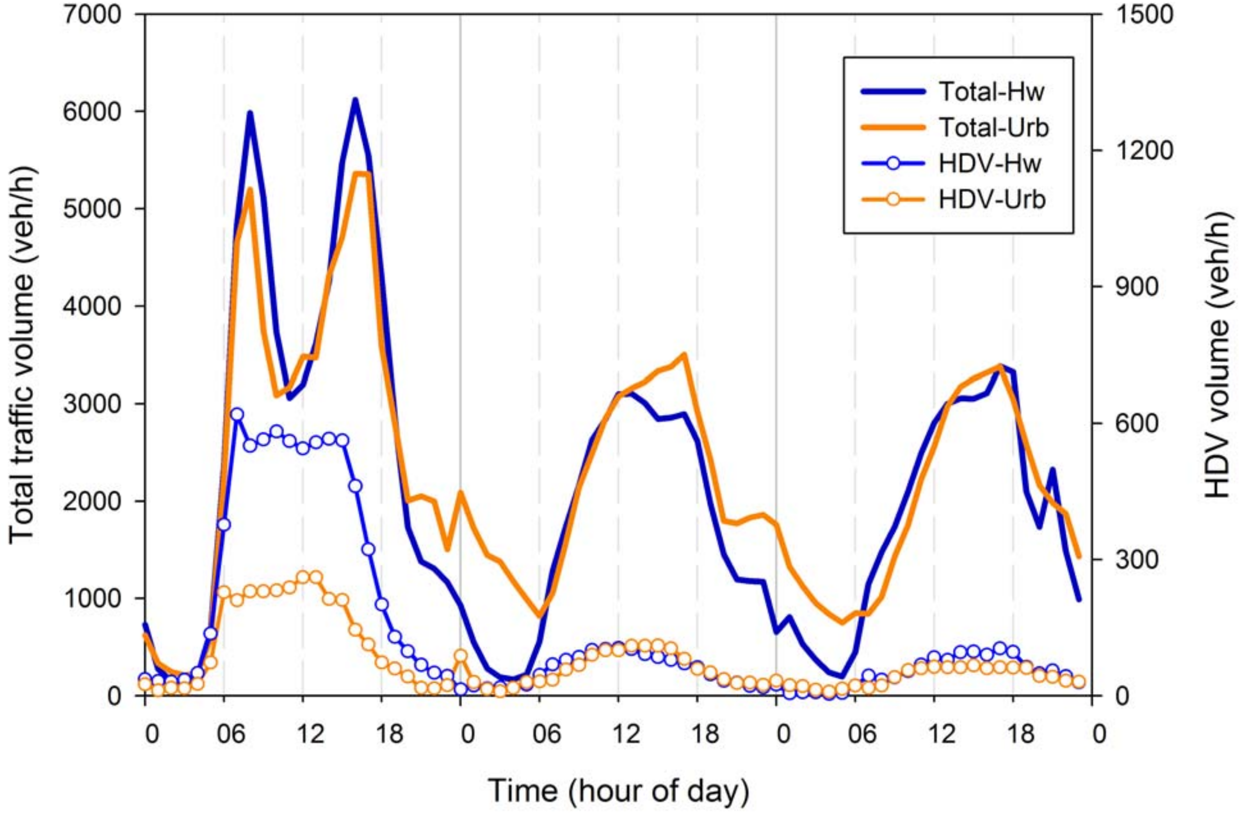


Field Design

- Location
  - urban site (Copenhagen)
  - highway site (30 km west of Copenhagen)
  - both sites equipped with kerbside and background stations
- Driving conditions
  - ca. 50 km/h at the urban site
  - ca. 100 km/h at the highway site
- Fleet
  - LDV (light duty vehicles, mainly gasoline)
  - HDV (heavy duty vehicles, mainly diesel)
- Measured parameters at both sites both stations
  - Gas phase : NOx (NO, NO_2), O_3
  - Particulate phase : Particle number size distribution in the size range between 10 – 700 nm, PM2.5, PM10
  - Meteorology : wind speed, wind direction, precipetation, temperature, relative humidity and solar radiation

Measurement Results

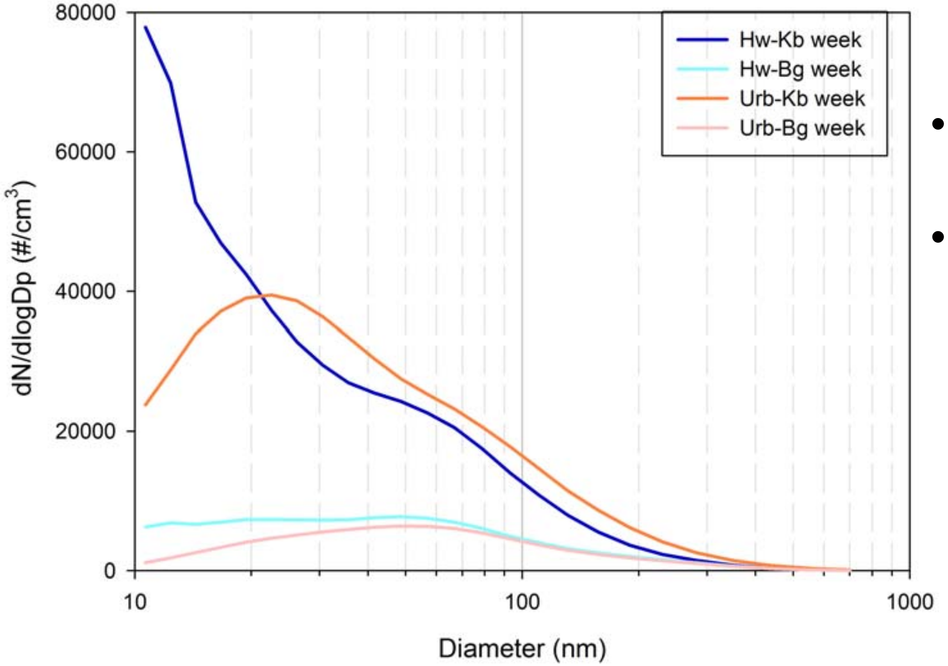
1.Traffic pattern



- Two distinct rush hour peaks during weekdays both sites
- Rush hour peaks are not reproduced by HDV share both sites
- Some traffic density during saturdays and sundays during nighttime at urban site

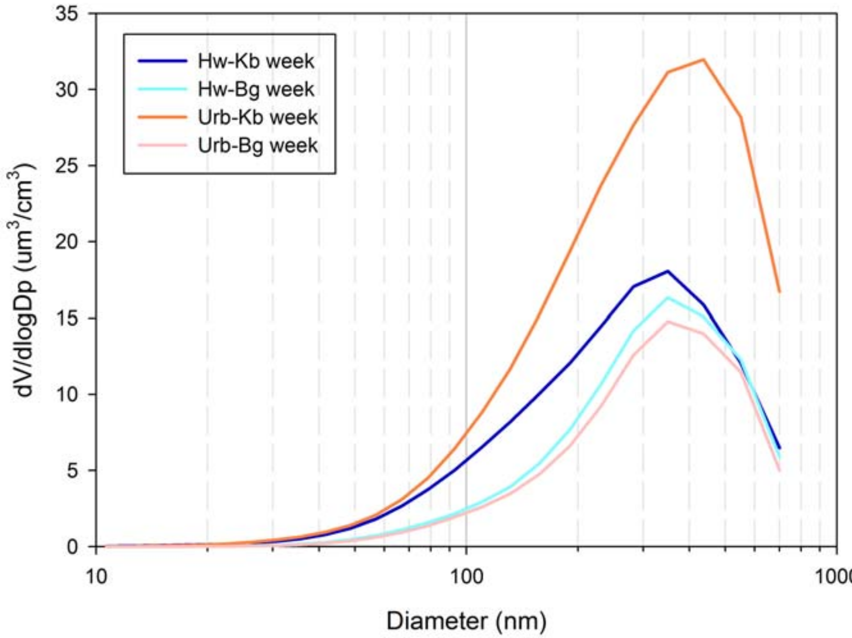
Measurement Results

2.Particle size distribution



PNumberSD (weekdays)

- Concentration of freshly formed particles much higher at highway site compared to urban site
- Shape of size distributions becomes similar for larger sizes



PVolumeSD (weekdays)

- Submicrometer particle volume much higher at urban site compared to highway site

Emission

1.Method

- Traffic contribution
- Dilution rate calculated by dispersion model with NOx as tracer
- Ordinary Least-Squares (OLS) approach (HDV/LDV)

$$\Delta C(t) = C_{kerbside}(t) - C_{background}(t)$$

$$EFP_i = \frac{\Delta C_i(t) D(t)}{N_{total}(t)}$$

$$N_{total}(t) \bullet EFP_i = n_{LDV}(t) \bullet EFP_{i(LDV)} + n_{HDV}(t) \bullet EFP_{i(HDV)} + \varepsilon_i$$

EFP_i emission factor per average vehicle for the pollutant of species i

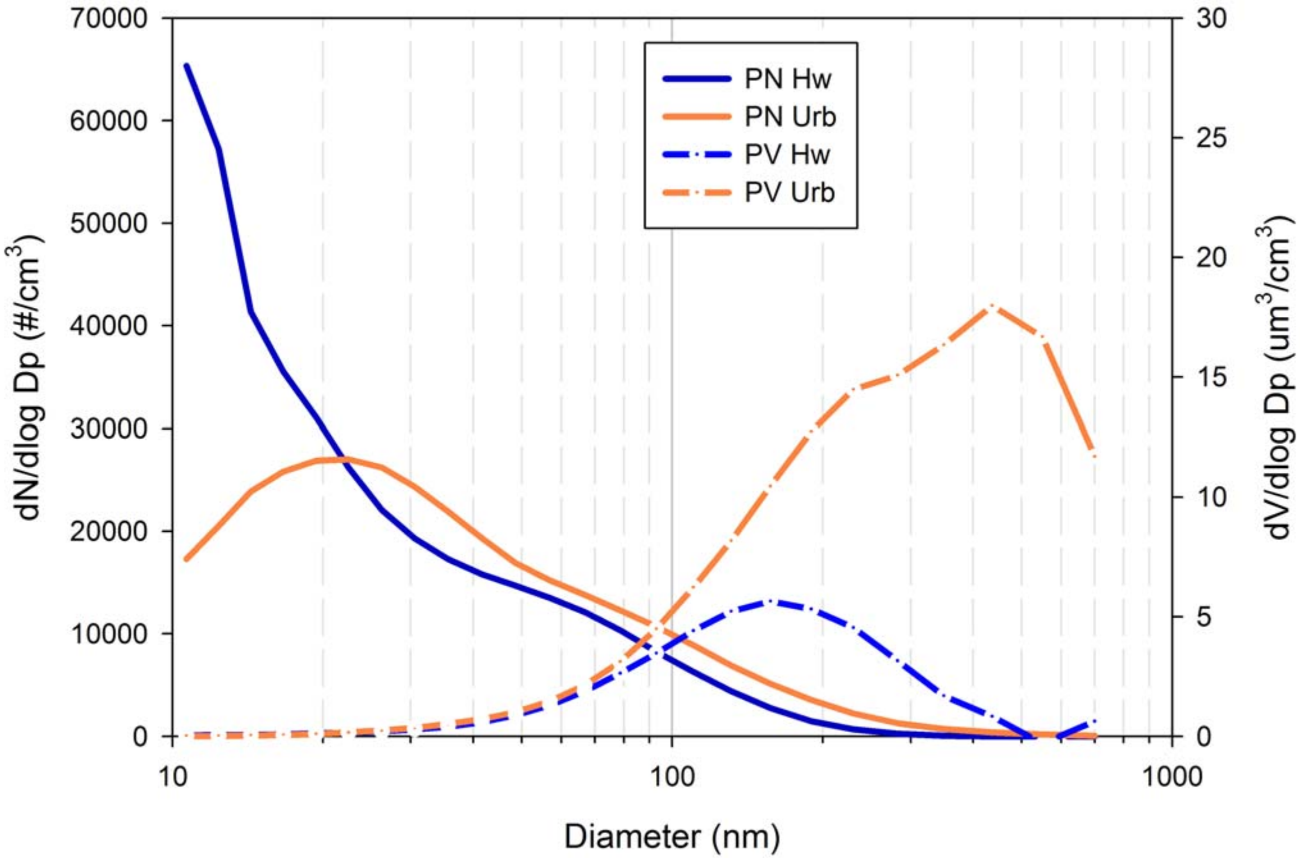
$\Delta C_i(t)$ concentration increment of species i

$D(t)$ dilution rate at time t (m^2/s)

$N_{total}(t)$ total number of vehicles passing at the site (vehicle/h)

Emission Results

2.Traffic contribution: $\Delta C = C_{kerbside} - C_{backgroun}$



PNumber/PVolume size distribution (weekdays)

- Higher contribution of PN for particles smaller than 20 nm in size at highway site compared to urban site
- Much higher emission of submicrometer particle volume at urban site compared to highway site

Emission Results

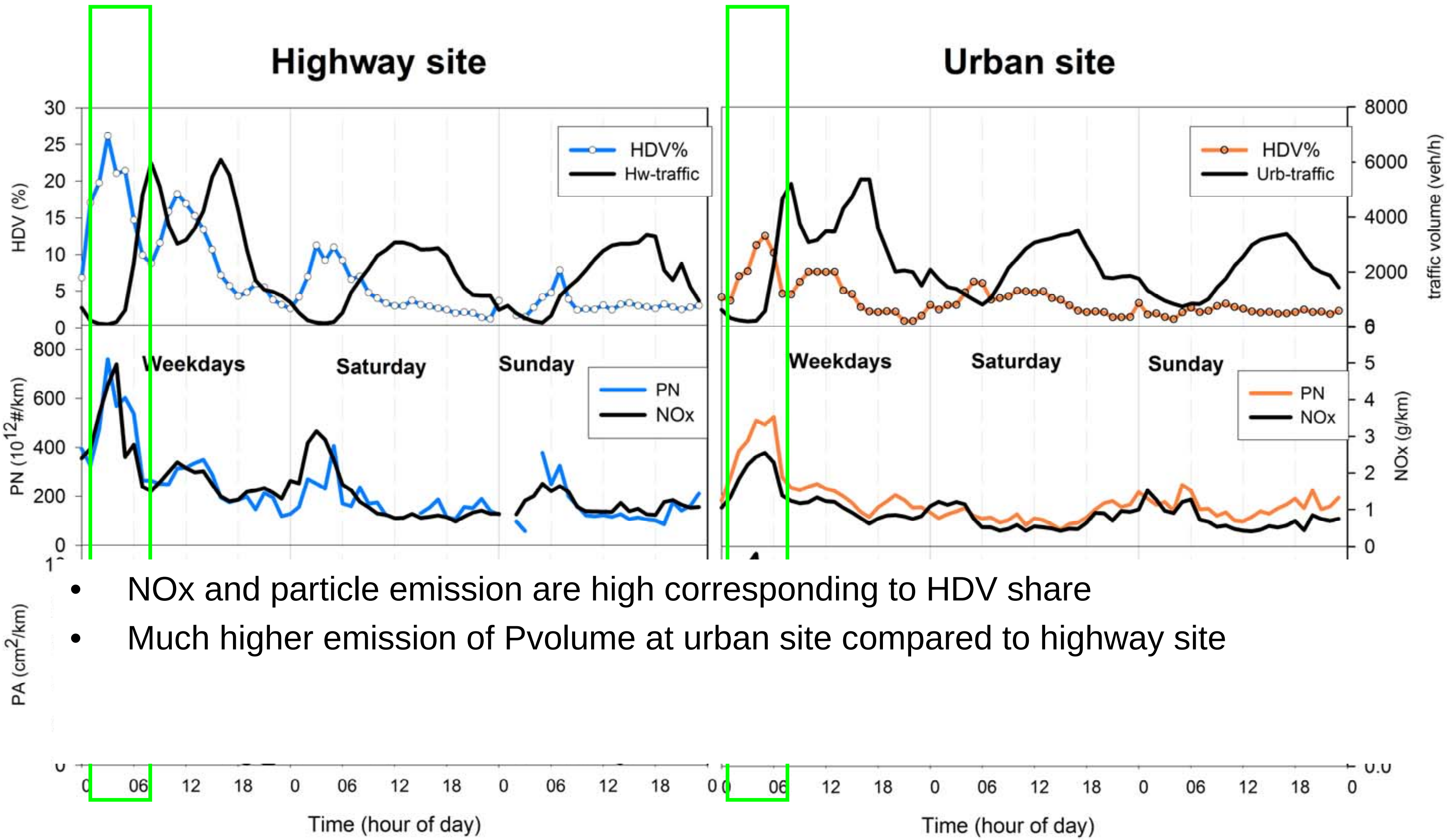
3. Emission factors (EF)

	Highway site			Urban site		
	EF (total)	EF(LDV)	EF(HDV)	EF (total)	EF(LDV)	EF(HDV)
NOx (g/km)	1.4 ±0.03	0.7 ±0.03	9.8 ±0.29	0.9 ±0.02	0.5 ±0.03	11.9 ±0.59
PNumber (10^12 p./km)	215.4 ±5.3	80.8 ±6.9	1749.7 ± 67.6	187.1 ±3.1	100.5 ±6.2	2206.4 ±128.2
Pvolume (cm^3/km)	0.03 ±0.001	0.01 ±0.001	0.25 ±0.01	0.09 ±0.001	0.05 ±0.003	0.95 ±0.055
PNumber/NOx	154	115	179	208	201	185
PVolume/NOx	0.02	0.014	0.025	0.1	0.1	0.08

- Ratio of PNumber emission factors HDV/LDV about 22
- PNumber/NOx are at the same magnitude at both sites
- PVolume/NOx are 5~10 times higher at urban site than at highway site

Emission Results

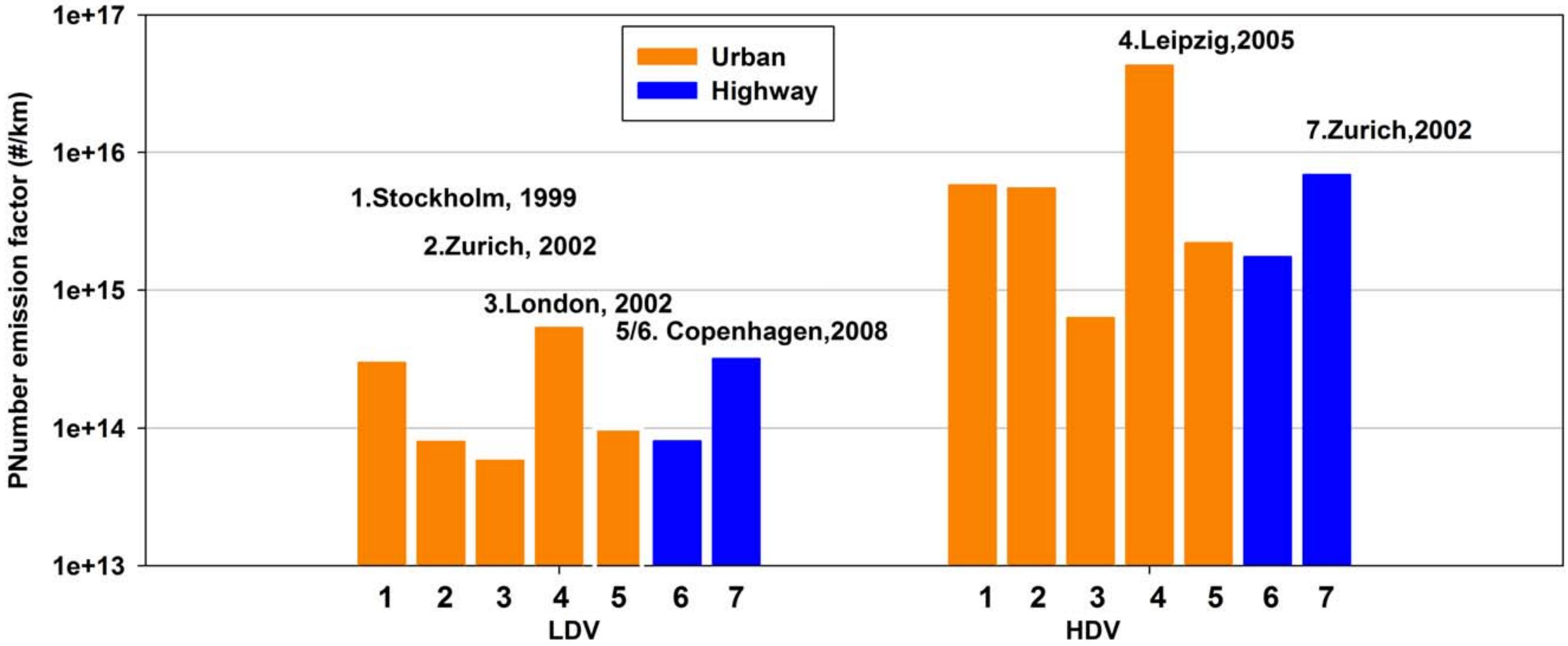
4. Emission factor Variation



- NOx and particle emission are high corresponding to HDV share
- Much higher emission of Pvolume at urban site compared to highway site

Emission Results

5. Emission factor comparision (1)

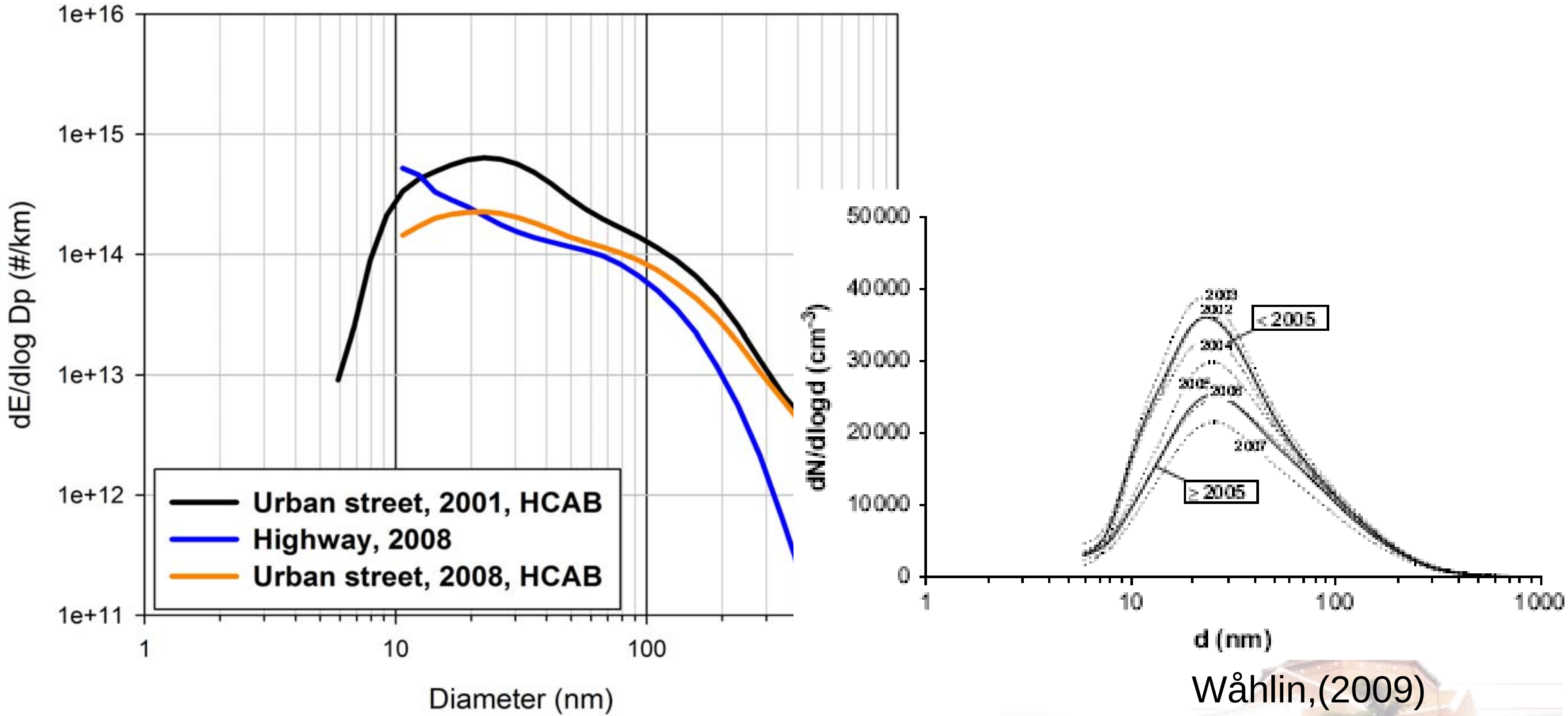


- Our results are in good agreement with other studies in Europe
- Ratio of Pnumber EF (HDV) to Pnumber EF (LDV) in the range of 10 to 80

Stickholm: Kristensson A. et al.(2004), Leipzig: Klose et al.(2009),
London: Jones A. and Harrison M.(2006), Zurich: imhof D. et al.(2005)

Emission Results

5. Emission factor comparision (2)

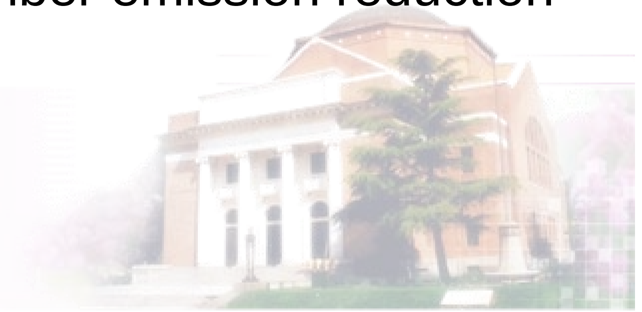


Wåhlin,(2009)

- Pnumber EF at HCAB distinctly decreased from 2001 to 2008 for particles less than 100 nm due to the transition to sulphur-free (<10 ppm) diesel fuel and petrol fuel in Denmark at the beginning of 2005

Summary

- PNumber emission factors for particles smaller than 20nm is higher at highway site compared to urban site
- Much more Pvolume is generated at urban site compared to higway site
- Emissin factors of HDV is about 20 times higher than Emissin factors of LDV for PNumber
- The ratio of PNumber emission factor to NOx emission factor is in the range of 150~210 X 10^{12} (particles/g/km)
- Emission factors found at urban site and highway site are in agreement with literature data
- Sulphur-free transition results in significant PNumber emission reduction for ultrafine particles at urban site



Thank You
For Your Time！

Meteorology condition

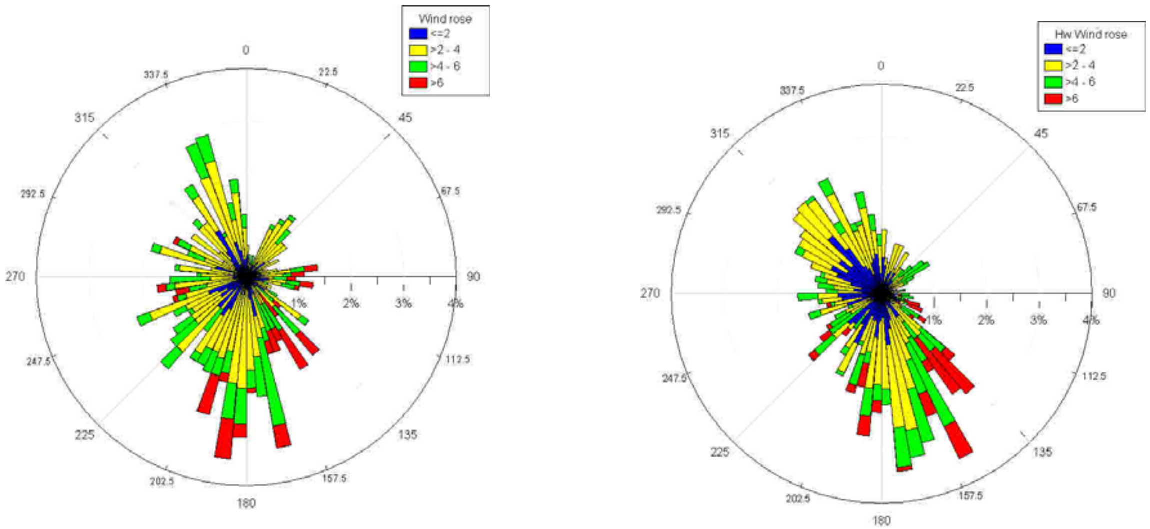


Fig. 2 Wind rose observed at the highway site (left) and the urban site (right).

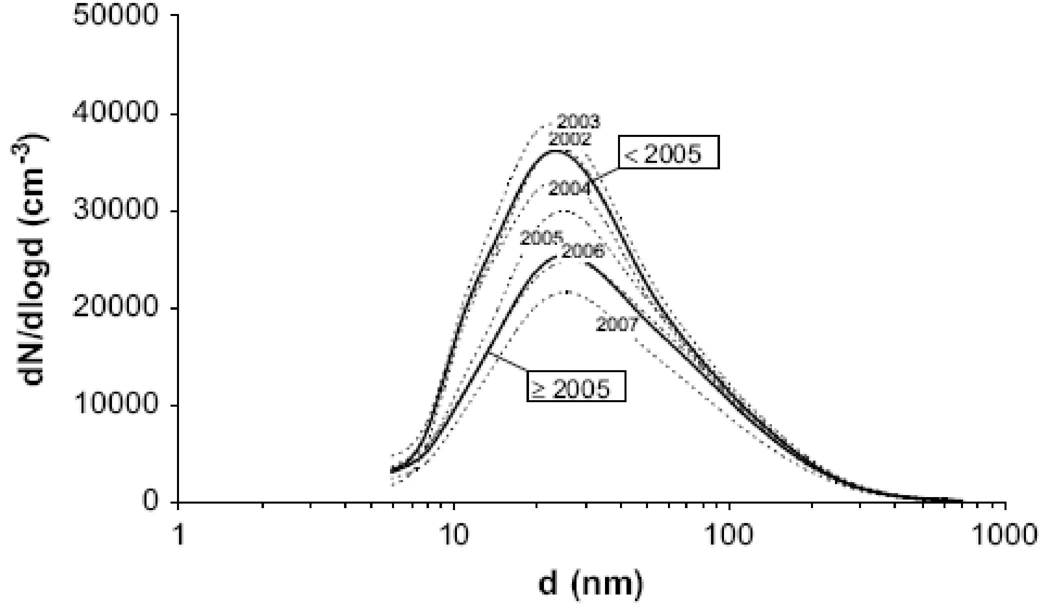


Fig. 1. The averages of the differential particle concentration dN/dlogd at H.C. Andersens Boulevard in the years 2002–2007 as function of the mobility diameter d. Also shown are the averages for the years 2002–2004 and for the years 2005–2007.

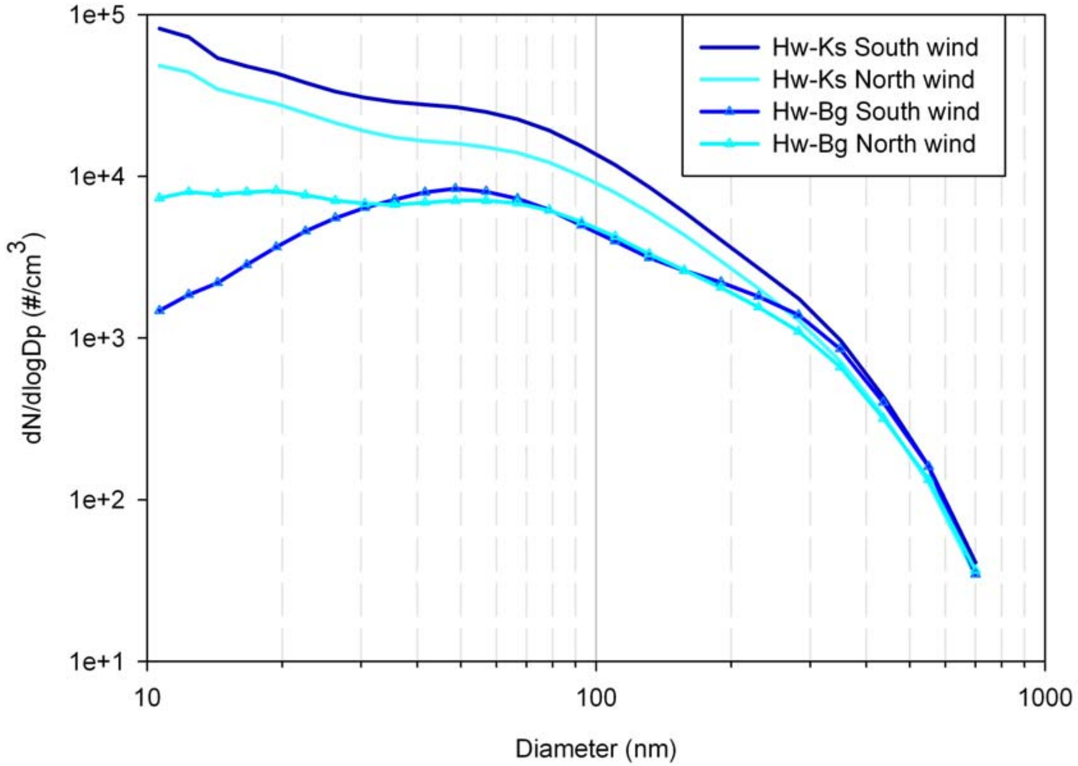


Fig. 10 Average particle number size distribution at the highway background and the highway kerbside stations at southern (105º -225º) and northern (225º -105º) winds (only weekdays included in the analysis).

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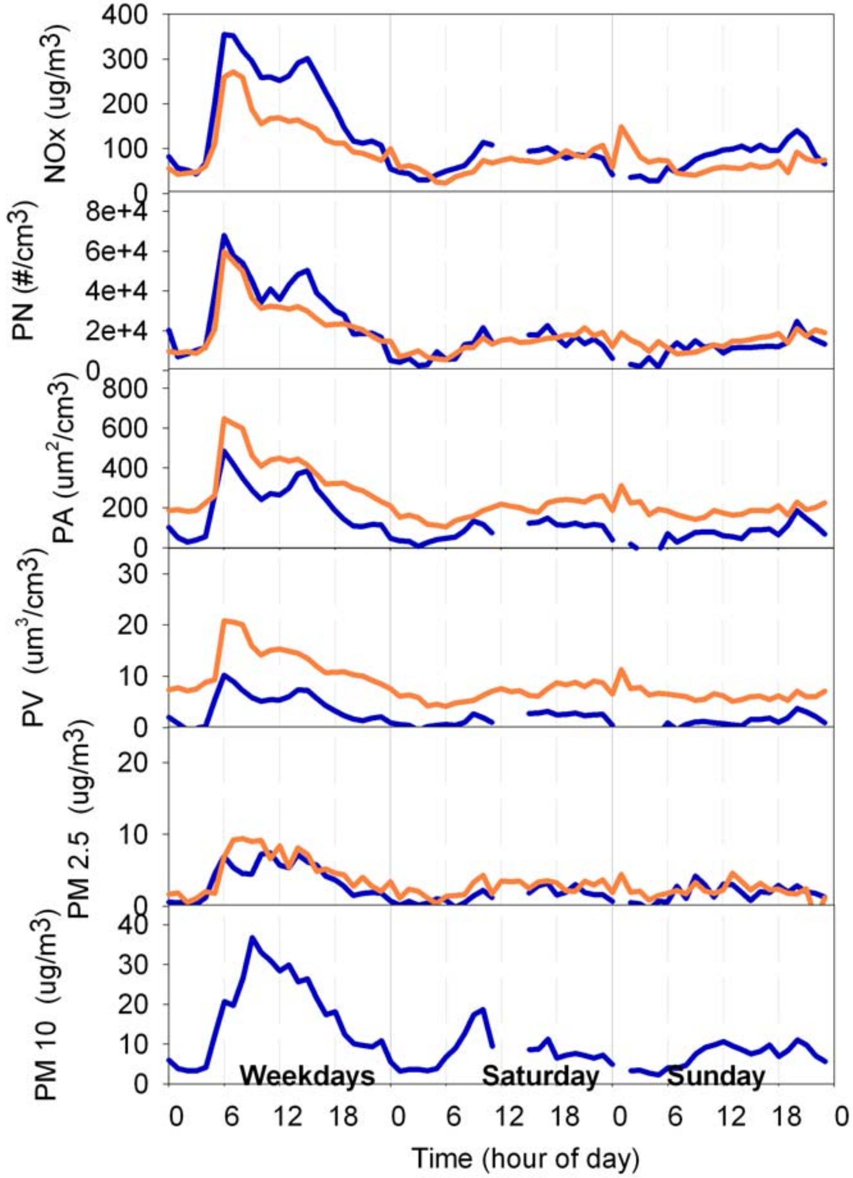
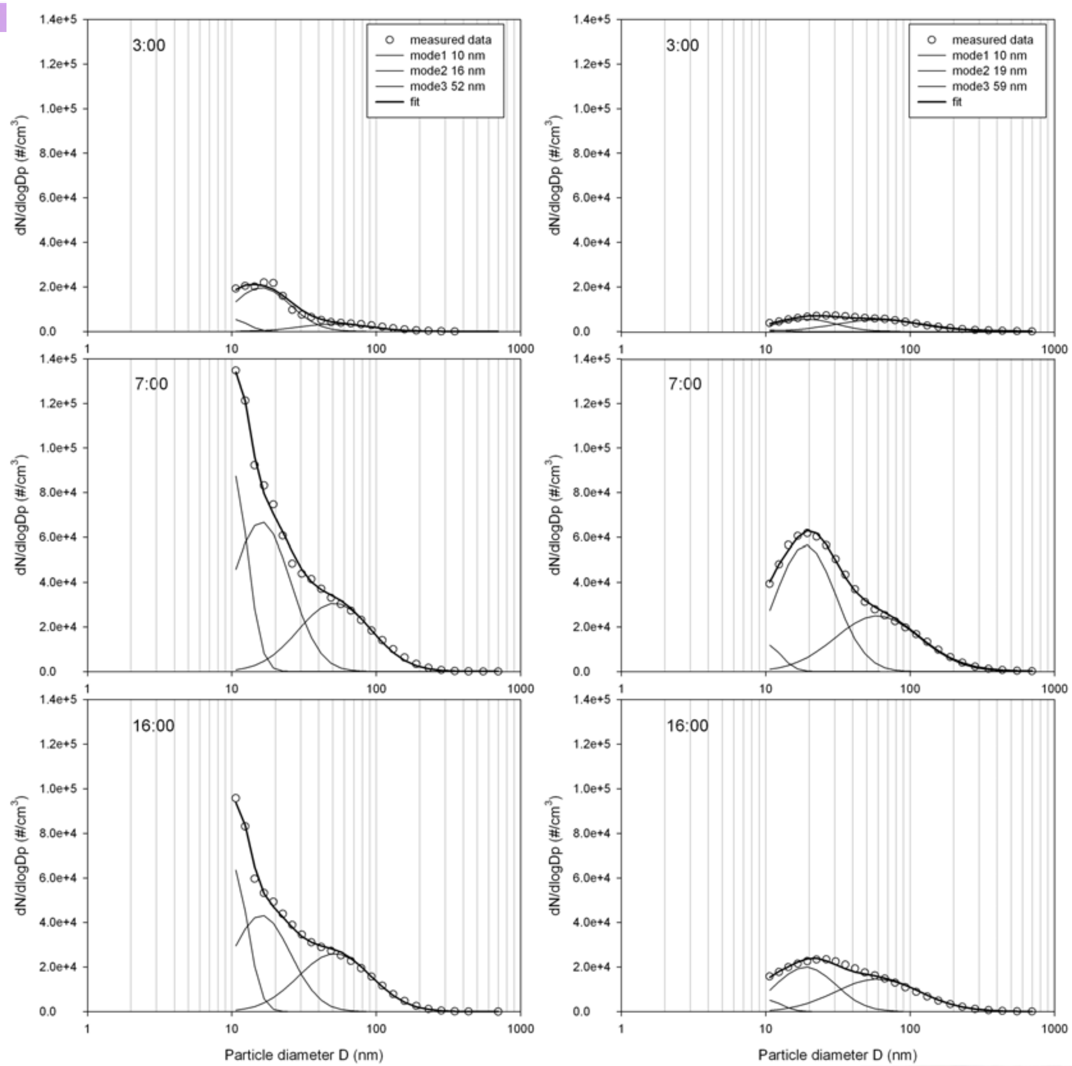


NOx (ug/m3)
400
300
200
100
0
PN (#/cm3)
8e+4
6e+4
4e+4
2e+4
0
PA (um2/cm3)
800
600
400
200
0
PV (um3/cm3)
30
20
10
0
PM 2.5 (ug/m3)
20
10
0
PM 10 (ug/m3)
40
30
20
10
0
Weekdays
Saturday
Sunday
0 6 12 18 0 6 12 18 0 6 12 18 0
Time (hour of day)


3:00
measured data
mode1 10 nm
mode2 16 nm
mode3 52 nm
fit
3:00
measured data
mode1 10 nm
mode2 19 nm
mode3 59 nm
fit
7:00
7:00
16:00
16:00
dN/dlogDp (#/cm3)
Particle diameter D (nm)
Particle diameter D (nm)

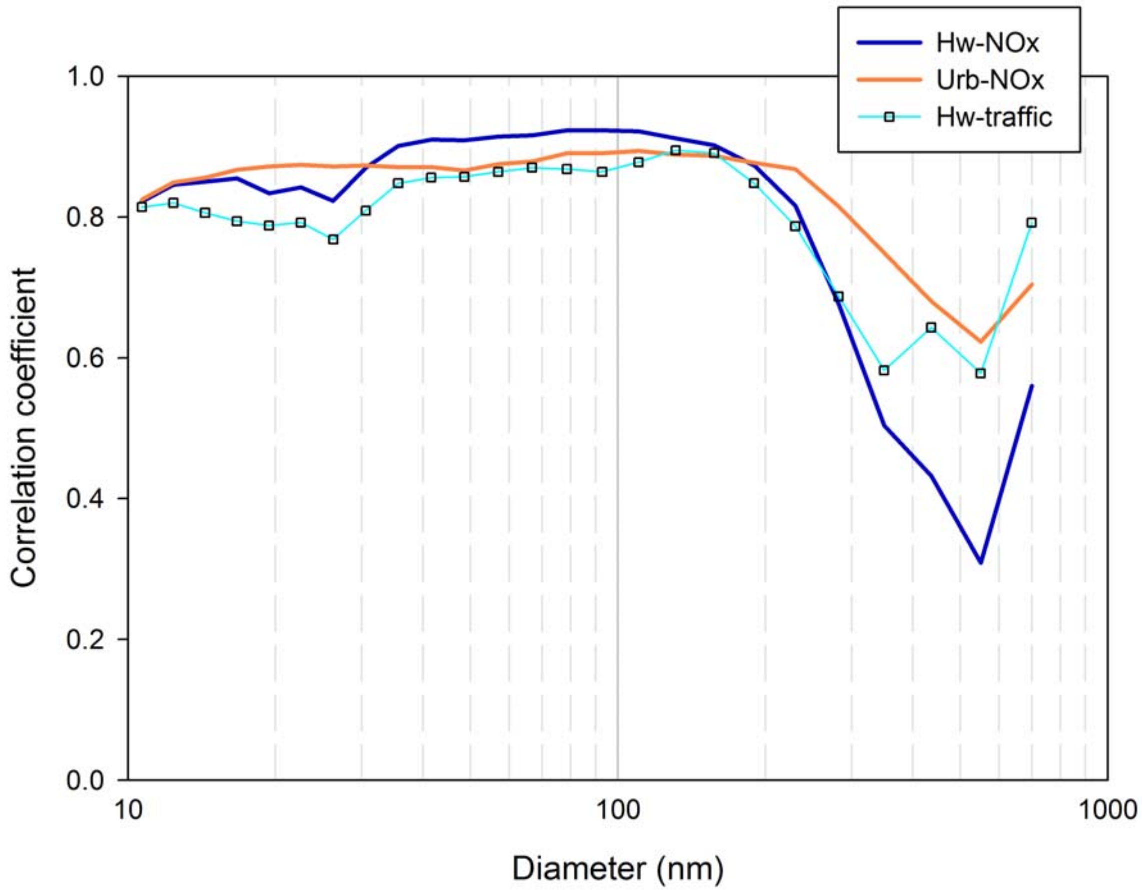
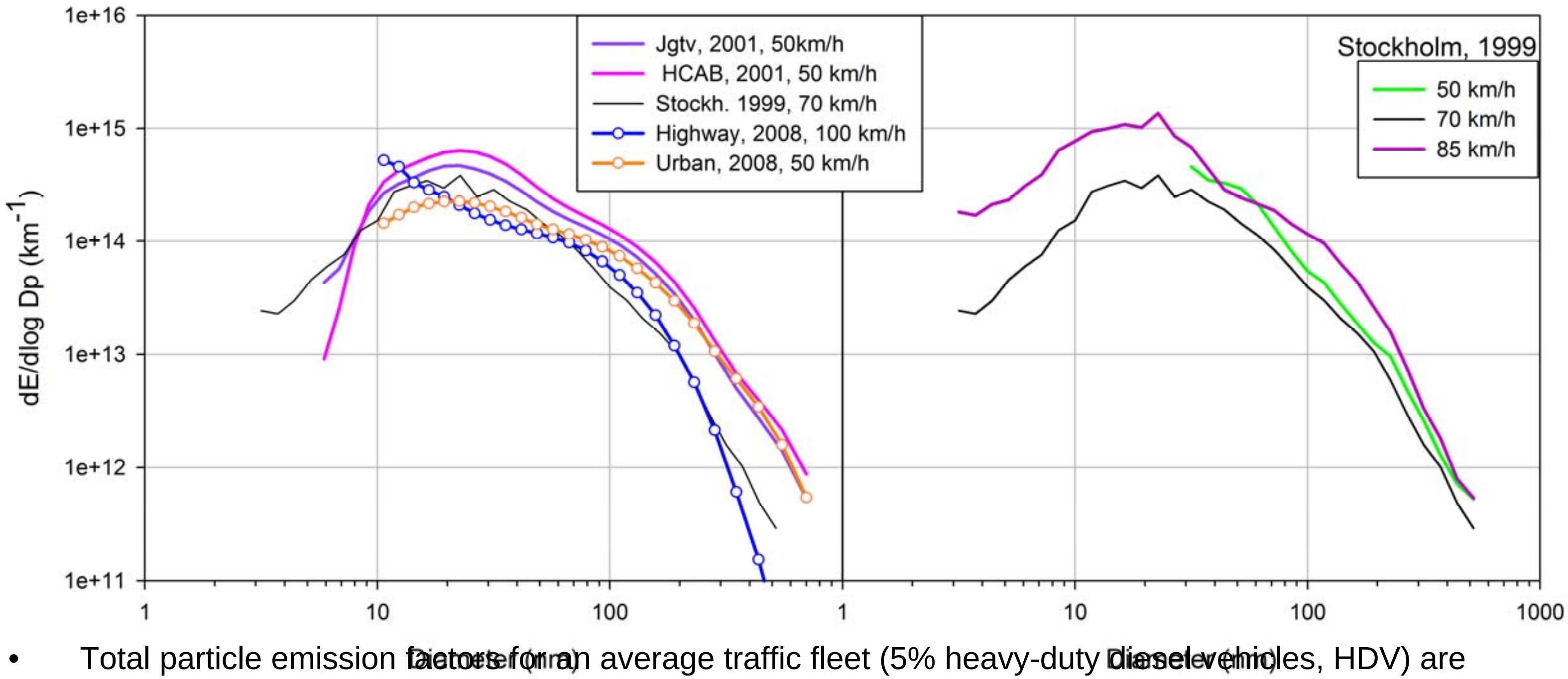


Fig. 14 Correlation coefficient of NOx contribution with particle number size distribution at the highway and urban sites, Correlation coefficient of traffic volume with particle number size distribution at the highway site.

Comparison: speed dependence?



- Total particle emission factors for an average traffic fleet (5% heavy-duty diesel vehicles, HDV) are typically ~300·1012 km-1 and ~400·1012 km-1 at Jagtvej and HCAB (speed limit 50 km·h-1) in our previous study, which are slightly higher than this study (215.4±5.3)1012 particles km-1at the highway site and (187.1±3.1) 1012 particles km-1 at the urban site.
- It notes that the particle number emission factors from HCAB distinctly decreased from 2001 to 2008 for particles less than 100 nm. due to the transition to sulphur-free (<10 ppm) diesel fuel and petrol in Denmark at New Year 2005, consisting with number concentration at kerbside station (HCAB, the same location of our urban street site) has been reduced by 27% from the period 2002-2004 to the period 2005-2008 (Wahlin, 2009).
- Delete the one from stockholm?