THE DANISH AIR QUALITY MONITORING PROGRAMME

Annual Summary for 2008

NERI Technical Report no. 752 2010

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
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Data sheet

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Abstract: The air quality in Danish cities has been monitored continuously since 1982 within the Danish Air Quality Monitoring (LMP) network. The aim is to follow the concentration levels of toxic pollutants in the urban atmosphere and to provide the necessary knowledge to assess the trends, to perform source apportionment, and to evaluate the chemical reactions and the dispersion of the pollutants in the atmosphere. In 2008 the air quality was measured in four Danish cities and at two background sites. Model calculations were also carried out to supplement the measurements. At several stations NO_2 and PM_{10} were found in concentrations above EU limit values, which the Member States have to comply with in 2005 and 2010. The concentrations for most pollutants have been strongly decreasing since 1982, however, only a slight decrease has been observed for NO_2 and O_3.

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Summary and Conclusion

This report presents results from the Danish Air Quality Monitoring Programme (LMP) for the year 2008. The monitoring programme is carried out by the National Environmental Research Institute (NERI) at University of Aarhus. It is based on measurements on 11 monitoring stations situated in the four largest cities in Denmark and in background areas in combination with use of model calculations using NERI's air quality models.

The aim of the monitoring program is to fulfil the Danish obligations for monitoring in relation to the air quality directives from EU. In accordance to this the program includes measurements of the concentrations and long term trends for SO_2, NO_x/NO_2, PM_{10}, lead, benzene, CO, ozone, arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons (PAH). The measurements and model calculations are used to evaluate the Danish air quality in relation to limit values and to determine sources to the different compounds. Moreover, the program serves as basis for evaluation of the effect of future regulations of emissions and as basis for various research projects related to air quality.

The concentrations were in 2008 almost the same as in 2007. Changes may mainly be due to meteorological conditions.

The limit value + the margin of tolerance for the annual average of NO_2 (44 µg/m^3 in 2008) was exceeded at both the two street stations in Copenhagen. The limit value (to be complied with in 2010) of the annual average of NO_2, was in 2008 exceeded at three out of four street stations. The NO_2 concentrations seem to have been almost constant during the last ten years. Model calculations at selected streets in Copenhagen and Aalborg indicated that the limit value + margin of tolerance were exceeded on several streets in central Copenhagen and Aalborg.

The limit value for the 35th highest daily average value for PM_{10} (50 µg/m^3) was exceeded at one station in 2008. Emissions in other European countries contribute significantly to the PM_{10} levels in Denmark. $PM_{2.5}$ was lower than the future limit value (25 µg/m^3) that is valid from 2015.

The ozone level was in 2008 almost the same as in 2007 at all rural and urban background stations and no clear trend is observed. The information threshold at 180 µg/m^3 was not exceeded. The target values for ozone were not exceeded, but the long-term objectives for both the max 8 hours concentration on 120 µg/m^3 and the AOT40 on 6000 (µg/m^3)·h were exceeded at almost all non-traffic stations. The O_3 pollution in Denmark is to a large extent caused by long distance transport of pollutants from other European countries.

The SO_2 and lead levels have been decreasing for more than two decades and are far below the limit values. The limit values for benzene and CO are not exceeded and the levels have been decreasing for the last decade.

Measurements of the concentrations of particle bound PAH were performed at H.C. Andersens Boulevard, Copenhagen. The average concentration of benzo[a]pyrene was 0,40 ng/m^3. The target value for benzo[a] pyrene (1 ng/m^3) was not exceeded in 2008.

Actual data, quarterly reports, annual and multi-annual summaries are available at the website of NERI
(http://www.dmu.dk/International/Air).

Danish summary - Dansk resumé

Rapporten præsenterer resultaterne for 2008 fra Overvågningsprogrammet for luftkvalitet i danske byer (LMP). Programmet, som udføres af Danmarks Miljøundersøgelser (DMU) ved Aarhus Universitet, er baseret på målinger ved 11 målestationer hovedsageligt placeret i de fire største danske byer i kombination med anvendelse af modelberegninger med DMU's luftkvalitetsmodeller.

Formålet med programmet er at opfylde de danske overvågningsforpligtelser i relation til EU's luftkvalitetsdirektiver. I henhold til disse måles koncentrationer af SO_2, NO_x/NO_2, PM_{10}, bly, benzen, CO, ozon, arsen, cadmium, kviksølv, nikkel og polyaromatiske kulbrinter (PAH) i luften i danske byer. Derudover følges udviklingen i koncentrationerne og kilderne til de enkelte stoffer vurderes. Endvidere anvendes målingerne til at vurdere om EU's grænseværdier for luftkvalitet er overholdt og til at vurdere effekten af allerede gennemførte tiltag. Desuden tjener resultaterne som grundlag for vurdering af effekt af mulige fremtidige tiltag og som grundlag for en række videnskabelige undersøgelser, fx vurdering af små partiklers effekt på sundheden.

Der er fastsat grænse- og målværdier for flere af de målte stoffer. Grænseværdierne skal overholdes fra 2005 eller 2010. Frem til da er det dog tilladt at overskride disse grænseværdier indenfor en fastsat tolerancemargin, som løbende reduceres. En detaljeret beskrivelse af gældende mål- og grænseværdier og deres gennemførelse findes i en bekendtgørelse fra Miljøministeriet (Miljøministeriet 2007). Bekendtgørelsen er baseret på EU-direktiverne (EC 1996, 1999, 2000, 2003 og 2005). En revision af luftrammedirektivet og de tre første datterdirektiver er blevet vedtaget i 2008 og det nye direktiv vil blive implementeret i 2008-2010. En af de væsentligste ændringer i det nye direktiv er, at der stilles krav om målinger af de fine partikler ($PM_{2.5}$), og at der er blevet indført grænseværdi for $PM_{2.5}$, der skal overholdes i 2015.

De væsentligste konklusioner fra overvågningsprogrammet i 2008 er følgende:

- Generelt var niveauerne i 2008 på samme niveau som i 2007. Ændringer kan for en stor del skyldes meteorologiske forhold.
- Indholdet af kvælstofdioxid (NO_2) overskred i 2008 grænseværdierne, som skal overholdes fra 2010 på tre målestationer (gadestationerne i København og Aarhus). Grænseværdien + tilladte margin (i 2008: 44 $\mu g/m^3$) blev i 2008 overskredet på begge gadestationerne i København. Ligeledes indikerer modelberegninger at grænseværdi + tilladte margin var overskredet på et stort antal gadestrækninger i centrum af København og på gadestrækninger i Aalborg.
- Grænseværdien for døgnmiddel af luftens indhold af partikler mindre end 10 µm (PM_{10}) blev i 2008 overskredet på én målestation i København (H.C. Andersens Boulevard). Grænseværdien for døgnmiddelværdien af PM_{10} er fastlagt til 50 $\mu g/m^3$, som kun må overskrides 35 gange om året.

- Indholdet af partikler mindre end 2.5 µm ($PM_{2.5}$) overskred ikke de kommende grænseværdier, som skal overholdes i 2015.
- Der er ikke fastsat egentlige grænseværdier for ozon (O_3), men kun "målværdier" og "langsigtede mål" (hensigtsværdier). De langsigtede mål blev overskredet på så godt som alle bybaggrunds- og landstationer.
- De øvrige målte stoffer findes i koncentrationer under grænseværdierne, og for flere stoffer (fx svovldioxid og bly) er indholdet faldet kraftigt siden målingernes start.
- Målinger af partikelbundet PAH blev fortaget på H.C. Andersens Boulevard, København. Middelværdien for benz[a]pyren var 0,40 ng/m^3. Målværdien på 1 ng/m^3 var ikke overskredet i 2008.

1 Introduction

The Danish Air Quality Monitoring Programme (LMP) originates back to the 1981. Today the programme comprises an urban monitoring network with stations in the four largest Danish cities and at two back ground stations in rural areas (figure 2.1). The results are used for assessment of the air pollution in urban areas. The programme is carried out in a co-operation between the National Environmental Research Institute at University of Aarhus (NERI), the Danish Environmental Protection Agency, the Municipalities of Copenhagen, Aarhus, Aalborg and Odense. NERI is responsible for the practical programme. The results are currently published in quarterly reports in Danish and they are summarised in annual reports in English with a Danish summary (e.g. last years report Kemp et al. 2008). The network, which was organized by the Environmental Protection Agency of the Municipality in Copenhagen, is now formally a part of the LMP program. Measurements are continued unchanged. Statistical parameters and actual data are accessible at the website: http://www.dmu.dk/-International/Air. Selected actual data are also available at tele-text, Danish National Television. Moreover, this report presents results from model calculation of air quality in Denmark carried out as supplement to the measurements in LMP.

Two national air quality monitoring networks are in operation in Denmark. Beside the LMP programme, a network in rural areas (the Danish Background Monitoring Program) was established in 1978 (fig. 2.1). NERI runs both programmes. At present gas and aerosol measurements are performed at five stations, and various ions are determined in precipitation collected at 9 sites.

The present Danish limit values are identical with the limit values laid down in the EU directives. The EU legislation consists of the framework directive (EC 1996), giving general rules for network design and limit value strategies, and a number of daughter directives giving limit values, target values, alert thresholds, reference methods and monitoring strategies for specific pollutants. The limit values are close to the recommendations (WHO, 2000) based on the known health effects of the pollutants. The limit values must in most cases be attained in 2005 or 2010. Until then a so-called margin of tolerance are added to the limit values. The margin of tolerance is gradually reduced to zero at the date of compliance. Daughter Directives for NO_2, SO_2, particulate matter (PM_{10}) and Pb (EC, 1999), CO and benzene (EC, 2000), O_3 (EC, 2002) and Cr, As, Cd, Hg and PAH (EC, 2005) has been adopted. In the following chapters the results from measurements and model calculations are compared to limit and threshold values. Please refer to the Directives for a detailed description of the exact definitions of the limit values, margin of tolerance, target values and alert thresholds.

A new directive has recently been finalised. This directive merges the framework directive and the first three daughter directives into a single streamlined and updated directive. One of the major changes in the new directive is that the new directive includes $PM_{2.5}$. The new directive is implemented in 2008 and will be fully implemented in 2010.

In 2009 problems with the measurements of particles were observed at H.C. Andersens Boulevard. Therefore, an extra quality control of the particle data from 2008 was carried out in order to ensure, that the measurements in 2008 did not have similar problems as those encountered in 2009. The problems observed in 2009 will be reported in further detail in the annual report for 2009 expected to be published during autumn 2010.

2 Measurements and model calculations

The measuring strategy is in short to place one or more pairs of stations in each city. One of the stations is located close (at the sidewalk) to a street lane with a high traffic density. The other is located within a few hundred meters from the street station, and is representative for the urban background pollution; it is not influenced by a single or a few streets or other nearby sources. In most cases the background stations are placed on rooftops. In addition, two rural stations monitor the pollution outside city areas. Further information about the program and results is found at the website: http://www.dmu.dk/International/Air.

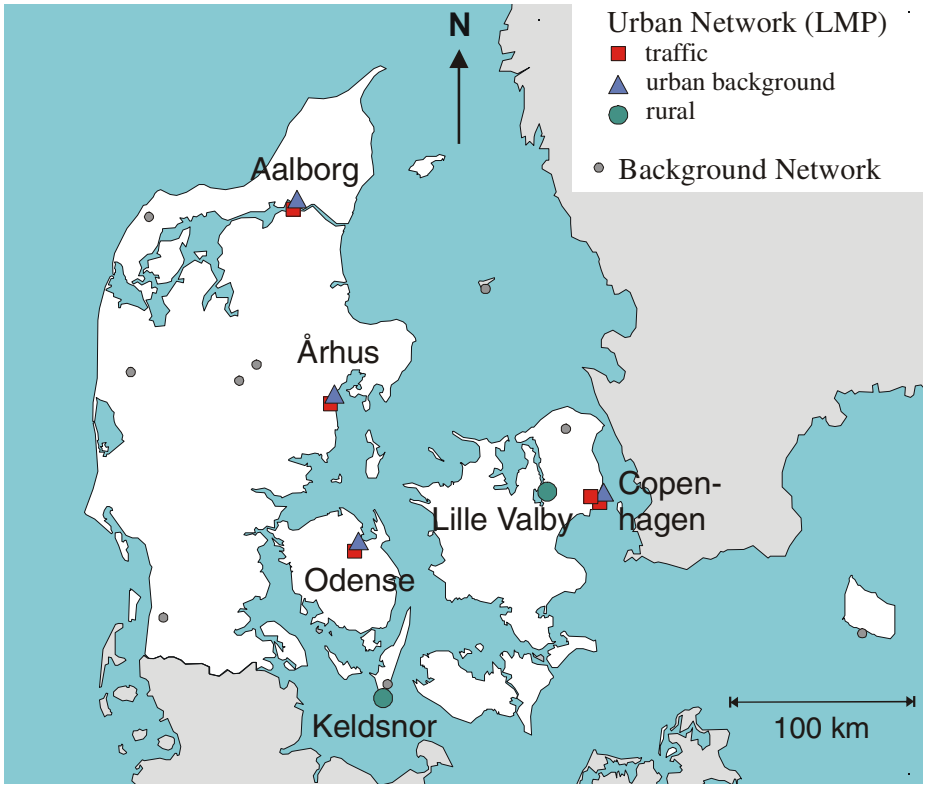

Figure 2.1 Monitoring stations in the two nation-wide air quality networks.

Table 2.1 Stations in the LMP network included in this report for 2008

Name	Street/location	Type
Copenhagen/1257	Jagtvej	Street
Copenhagen/1259	H.C. Ørsted Institute	Urban background
Copenhagen/1103	H.C. Andersens Boulevard	Street
Århus/6153	Banegårdsgade	Street
Århus/6159	Valdemarsgade	Urban Background
Odense/9155	Albanigade	Street
Odense/9159	Town hall in Odense	Urban background
Aalborg/8151	Vesterbro	Street
Aalborg/8158	Østerbro	Urban background
Lille Valby/2090	-	Rural
Keldsnor/9055	-	Rural

The following compounds were measured in 2008:

- NO, NO_x including the derived compound NO_2 (NO_2=NO_x-NO) and particle mass (either PM_{10} or $PM_{2.5}$) were measured at all stations. PM was measured by means of β-absorption.
- Elements (heavy metals) in PM were measured at Copenhagen/1103, Copenhagen/1257, Copenhagen/1259, Århus/6153, Århus/6159 and Lille Valby/2090.
- Additionally PM_{10} was measured at Copenhagen/1103, -/1257 and -/1259 by means of TEOM. Part of these measurements was carried out in a research project funded by the Danish EPA.
- Additionally $PM_{2.5}$ was measured at Copenhagen/1103, -/1259 and Lille Valby/2090 by means of TEOM. Part of these measurements was carried out in a research project funded by the Danish EPA.
- O_3 was measured at all urban background and rural stations, and at the street stations Copenhagen/1257 and Copenhagen/1103
- CO was measured at all street stations, the urban background station, Copenhagen/1259 and the rural site Lille Valby /2090.
- Benzene and Toluene were measured at Copenhagen/1103 and Copenhagen/1257 using passive sampling on a weekly basis. The measurements started in August.
- PAH were measured at Copenhagen/1103.
- SO_2 was measured at Aalborg/8151 and at Copenhagen/1103. The main purpose was to monitor episodic high concentrations.
- The meteorological parameters - temperature, wind speed and direction, relative humidity and global radiation - were measured at all urban background stations.

The pollutants are described in the appendix 1.

Measurements of gasses (NO, NOx, NO2, O3, CO, SO2) were recorded as ½-hour averages. Particle mass (PM10 and PM2.5) were measured both as 24 hour averages using beta measurements and at ½-hour averages using TEOM (only part of particle mass). Elements in the particles and PAH were measured as 24 hour averages. Benzene and Toluene were measured weekly by passive sampling. Besides this volatile organic compounds were sampled at 24 hour averages. However, due to technical problems with the analysis no results can be reported for 2008.

Short descriptions of the measured pollutants are given in the appendix 1. The actually applied measurement methods are listed at the website: http://www.dmu.dk/International/Air.

In LMP the measurements at fixed measurement stations are supplemented with model calculations using the Thor modelling system. This is an integrated model system, capable of performing model calculations at regional scale from urban background scale and down to individual street canyons in cities – on both sides of the streets (thor.dmu.dk). At present the system includes global meteorological data from National Centres for Environmental Prediction, United States, which is used as

input for the four dimensional data assimilation (FDDA) in the meteorological model MM5v3 (Grell et al., 1995). The meteorological data from MM5v3 is used to drive the air pollution models, including the Danish Eulerian Hemispheric Model, DEHM , the Urban Background Model, UBM (Berkowicz, 2000b) and the Operational Street Pollution Model, OSPM (Berkowicz 2000a). DEHM is providing air pollution input data for UBM which again is providing air pollution input data to OSPM. Further details about the system can be found in Brandt et al. (2001 and 2003).

Model calculations of air quality on national scale is carried out using DEHM (version 5.0), which is an Eulerian model where emissions, transport, chemical reactions, physical transformations, and depositions of air pollutants are calculated in a three dimensional net of grid cells covering the northern hemisphere. The transport of air pollutants is calculated on the basis of meteorological data from a weather forecast model and takes place in and out of the individual grid cells in both horizontal and vertical directions. The calculations of air quality in Denmark are carried out with a geographical resolution of 6 km x 6 km in the horizontal plane. In the vertical direction the model is divided into 20 layers covering the lowest 15 km of the atmosphere. Of these the lowest layers are relatively thin (60 m) while the upper layers are relatively thick (2000 m). The model includes a comprehensive chemical scheme for calculation of the chemical reactions in the bottom part of the atmosphere. The model calculations for 2008 are carried out using meteorological data from the meteorological model MM5v3 (Grell et al., 1995). The emission inventories used in DEHM have a geographical resolution on 6 km x 6 km for Denmark and 17 km x 17 km for the remaining part of Europe. The emissions are based on Danish national emission inventories for the year 2007 made by NERI (www.dmu.dk) and international emission inventories for the year 2007 collected and distributed by EMEP (emep.int).

The Urban Background Model, UBM, calculates the urban background air pollution based on emission inventories with a spatial resolution of 1 km x 1 km and based on input data from DEHM concerning the regional background. UBM is suitable for calculations of urban background concentrations when the dominating source is the road traffic. The model includes a simple scheme for calculation of the dispersion and transport of the air pollutants and a simple chemical model accounting for oxidation of nitrogen monoxide by ozone based on an assumption of photochemical equilibrium on the time scale of the pollution transport across the city area. The model is described in detail in Berkowicz (2000b).

Finally, the street canyon model OSPM (http://ospm.dmu.dk/) is used to calculate the air pollution at 2 m height at the side walks of selected streets. Meteorological data from the meteorological model MM5 and air pollution concentrations from UBM are used as input to the model. The model includes emissions from traffic, simple chemical reactions describing the reactions of air pollutants in the street canyons and the dispersion of the air pollution in the street canyon (due to meteorological conditions and the moving traffic).

The traffic emission data used for the calculations with UBM and OSPM is based on NERI's traffic database with traffic volumes on all road links in Denmark for the year 2005 together with emission factors from the latest version of the COPERT IV model applied for 2008 conditions. The input data for the OSPM model on traffic volume and street configurations are generated using the AirGIS system (Jensen et al., 2001; http://airgis.dmu.dk).

The model calculations for 2008 for Copenhagen have been carried out using the full model calculation system based on DEHM, UBM, and OSPM. The calculations were carried out in order to determine the NO_2 concentration in 138 streets with meteorological and emission data as input data to the three models.

In Aalborg this modelling approach underestimated measured urban background concentrations. Therefore, emissions for the UBM model were scaled up and calibrated to the measured urban background level at the monitoring station in Aalborg prior to the calculation of the NO_2 concentrations for the 32 selected streets using OSPM.

3 Nitrogen oxides

3.1 Annual Statistics

Table 3.1 Nitrogen dioxide (NO_2) in 2008. All parameters are calculated with hourly averages.

Unit: µg/m^3	Number	Average	Median	98. percentile	19. highest
Traffic:					
Copenhagen/1257	6422	45*)	40	114	149
Copenhagen/1103	8145	55*)	49	126	169
Århus/6153	8263	41	37	94	120
Odense/9155	8648	29	22	93	136
Aalborg/8151	7648	40	34	107	138
Urban Background:					
Copenhagen/1259	7985	20	17	53	79
Århus/6159	8592	19	16	59	81
Odense/9159	7951	16	13	49	73
Aalborg/8158	8753	17	12	65	94
Rural:					
Lille Valby/2090	8235	11	8	34	50
Keldsnor/9055	8069	9	6	32	51
Limit values/limit value + margin of tolerance for 2008	>7884	40/44			200/220

*) Limit value + margin of tolerance exceeded.

Table 3.2 Nitrogen oxides (NO_x=NO+NO_2) 2008. All parameters are calculated with hourly averages.

Unit: µg/m^3 (as NO_2)	Number	Average	Median	98. percentile	19. highest
Traffic:					
Copenhagen/1257	6422	96	75	323	523
Copenhagen/1103	8146	115	94	351	537
Århus/6153	8264	89	72	286	508
Odense/9155	8648	66	39	316	543
Aalborg/8151	7648	112	80	420	681
Urban Background:					
Copenhagen/1259	7985	25	19	81	142
Århus/6159	8596	27	19	118	253
Odense/9159	7953	22	16	84	225
Aalborg/8158	8753	23	13	120	310
Rural:					
Lille Valby/2090	8263	12	9	42	75
Keldsnor/9055	8094	10	7	38	62

The limit values are based on EU Council Directive 1999/30/1999 (EC 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

3.2 Episodes

Table 3.3 Episodic results for Nitrogen dioxide (NO_2) in 2008. All parameters are calculated with hourly averages.

Unit: µg/m^3	Max. 3 hours	Date	Hour	Max. hour	Date	Hour
Traffic:						
Copenhagen/1257	206	081007	6	302	081007	7
Copenhagen/1103	191	080510	0	272	081007	7
Århus/6153	140	081030	7	201	081007	8
Odense/9155	144	081030	7	167	081030	8
Aalborg/8151	138	080423	5	215	080423	6
Copenhagen/1259	107	080510	0	132	080510	1
Århus/6159	83	081030	7	107	080506	21
Odense/9159	73	080326	22	104	080510	1
Aalborg/8158	102	081223	9	131	080423	6
Lille Valby/2090	56	080210	18	65	080424	6
Keldsnor/9055	55	080210	23	69	080510	16
Alert threshold	400	-		-	-	

Table 3.4 Episodic results for Nitrogen oxides ($NOx=NO+NO_2$) 2008. All parameters are calculated with hourly averages.

Unit: µg/m^3 (as NO_2)	Max. 3 hours	Date	Hour	Max. hour	Date	Hour
Traffic:						
Copenhagen/1257	482	081007	12	1529	081007	7
Copenhagen/1103	413	081007	10	1380	081007	7
Århus/6153	390	081030	13	1275	081007	8
Odense/9155	321	081030	13	957	080925	7
Aalborg/8151	388	081211	27	803	081103	10
Copenhagen/1259	80	080926	12	228	080925	22
Århus/6159	244	081030	13	503	081030	9
Odense/9159	156	081031	38	434	081031	21
Aalborg/8158	183	081103	15	447	080918	7
Lille Valby/2090	52	080410	12	136	080410	7
Keldsnor/9055	34	081130	10	188	080430	12

The Alert threshold for maximum 3 hours concentration of NO_2 is given in EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The "Max 3 hour" values are defined and calculated in the following way: First find the lowest one hour value for all consecutive three-hours periods. Second find the highest of these lowest one hour values which is defined as the "Max 3 hours" values, which is listed in table 3.3 and 3.4.

3.3 Trends

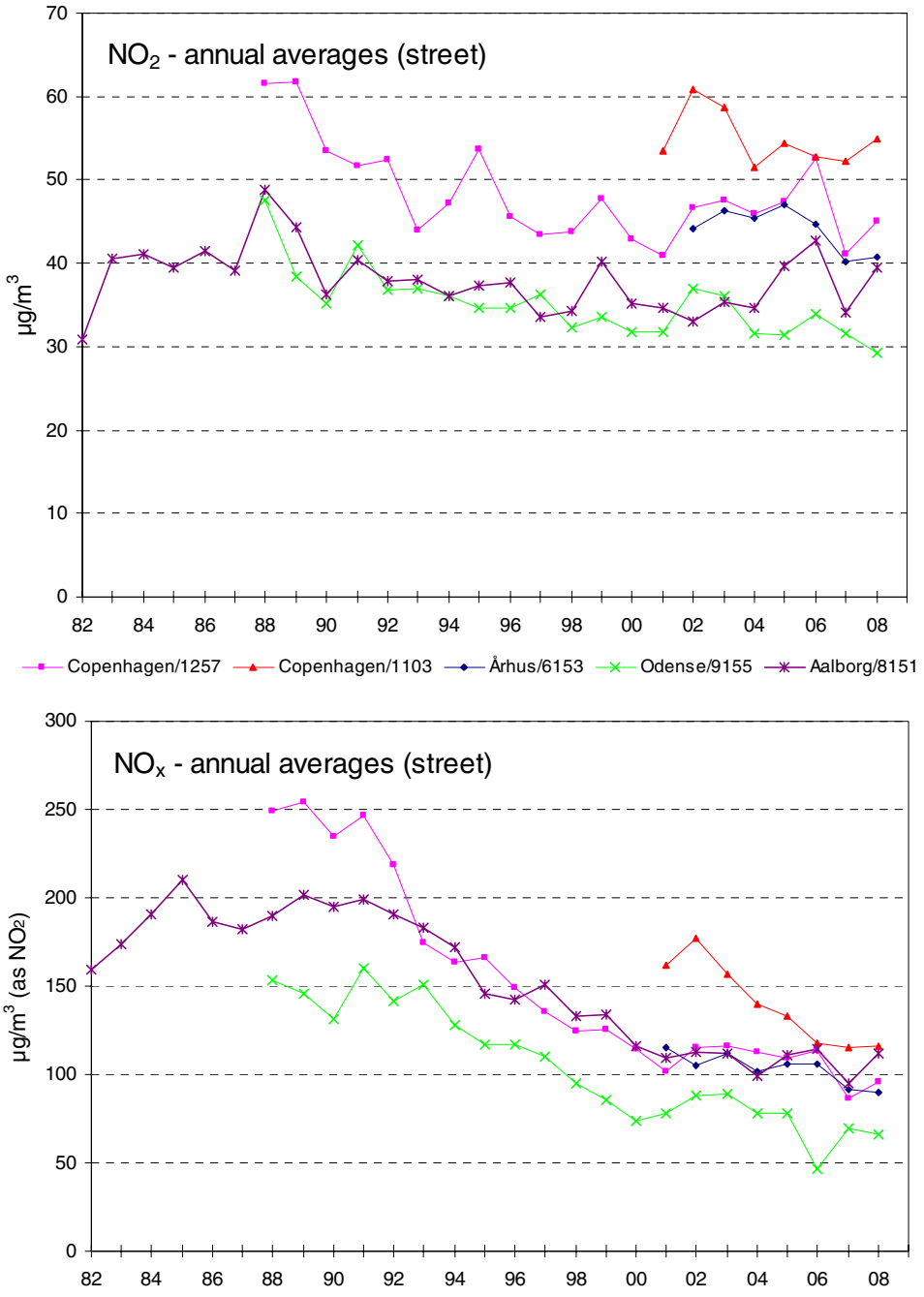

Figure 3.1 The graphs show the time series for the annual average values measured at street stations. Previous results from Copenhagen/1103 can be found at the homepage of Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk)

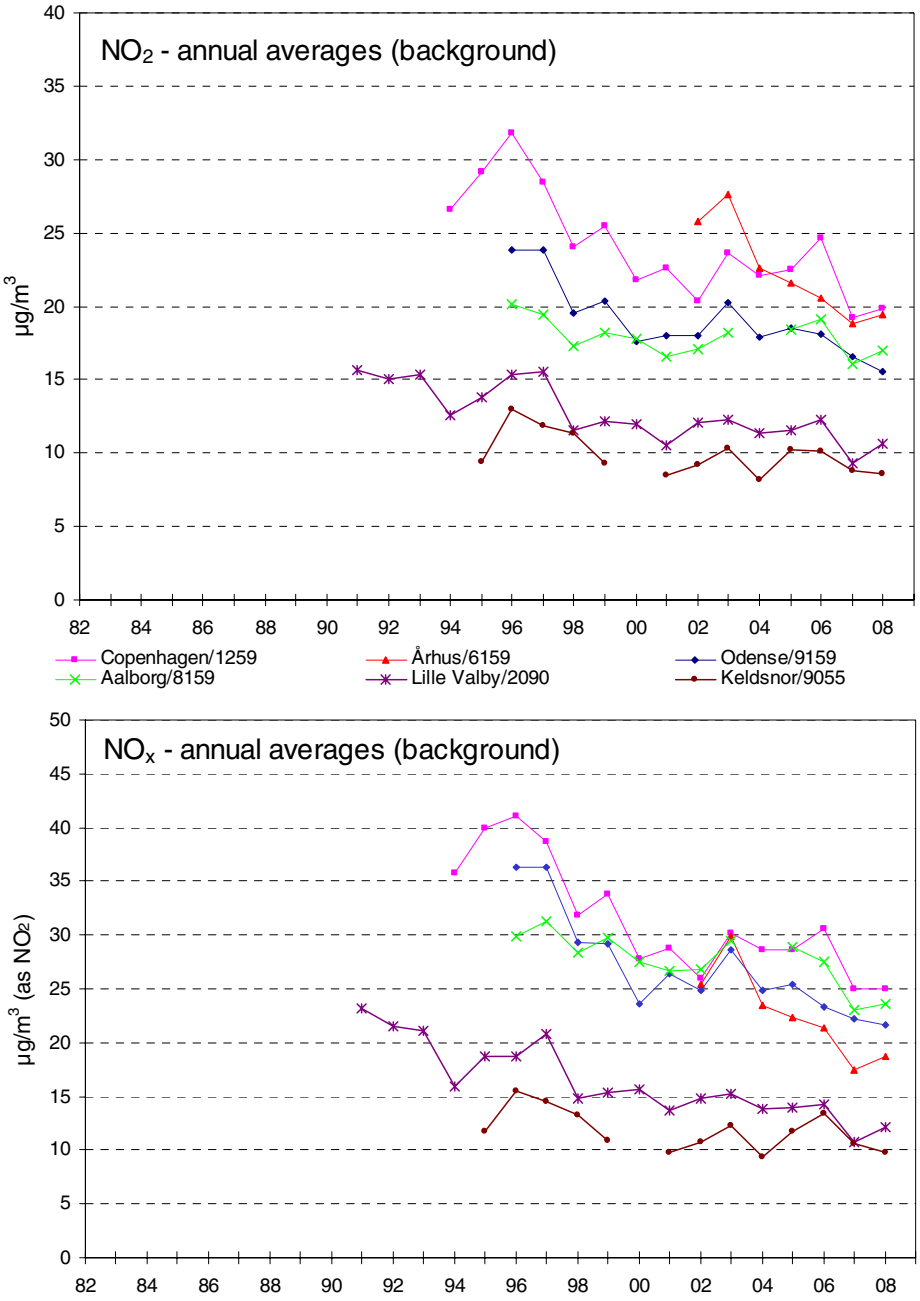

Figure 3.2 The graphs show the time series for the annual average values measured at urban background and rural stations.

3.4 Results from model calculations

Model calculations have been performed for selected streets in Copenhagen (capital) and Aalborg (fourth largest city) as well as for the entire country.

The selected streets represent busy streets that are street canyons. Concentrations are elevated in these streets due to high emission loads and restricted dispersion conditions. 138 streets were selected in Copenhagen and 32 in Aalborg. Average Daily Traffic was between 10,000 and 67,000 in Copenhagen and between 3,500 and 25,000 in Aalborg.

Model calculations have been performed for the annual concentrations and the 19th highest concentrations of NO_2 to be able to compare with limit values. The air quality limit value plus margin of tolerance in 2008 for the annual mean is 44 µg/m^3 and 220 µg/m^3 for the 19th highest concentration. The number of exceedances is also given.

An interlinked modelling approach has been applied. The Danish Eulerian Hemispheric Model (DEHM) calculates regional background concentrations, the Urban Background Model (UBM) calculates the urban background concentrations based on DEHM data, and the Operational Street Pollution Model (OSPM) calculates street concentrations based on UBM data. The emission data for the DEHM model are based on various international emission inventories, and emissions for the UBM model are based on the national emission inventory that has been redistributed on a 1 km x 1 km grid. Road emissions are based on the COPERT IV emission model. This model is also integrated into the OSPM model.

In Aalborg this modelling approach underestimated measured urban background concentrations. Therefore, emissions for the UBM model were scaled up and calibrated to the measured urban background level at the monitoring station in Aalborg.

OSPM calculations have been compared to measured NO_2 concentrations at street monitoring stations in Copenhagen (Jagtvej and H.C. Andersens Boulevard) and in Aalborg (Vesterbro). At all stations the model predicts NO_2 concentrations within +/- 7%.

3.4.1 Model calculations for Copenhagen

The annual concentrations and the 19th highest concentrations of NO_2 for Copenhagen in 2008 are shown in Figure 3.3 and 3.4, respectively.

In 2008 the limit value for the annual mean concentration plus margin of tolerance was exceeded in 58 out of the 138 selected streets in Copenhagen (Figure 3.3). In 2007 the number of streets exceeding the limit value plus margin of tolerance was only 35. The reasons for the increase between 2007 and 2008 are:

1. The limit value plus margin of tolerance for the annual mean concentration of NO_2 has decreased from 46 µg/m^3 in 2007 to 44 µg/m^3 in 2008. This decrease will naturally lead to a higher number of streets exceeding the limit value plus margin of tolerance in 2008 compared to 2007. If the limit value plus margin of tolerance had been 44 µg/m^3 in 2007, then the number of streets exceeding the limit value plus margin of tolerance would have been 53. Roughly the same level as in 2008.

2. There has been an increase in the amount of directly emitted NO_2 from 2007 to 2008 despite decrease in NO_x emissions from traffic. The reason is that there has been an increase in the number of diesel-powered passenger cars that are equipped with oxidizing catalysts. These cars emit a large fraction of NO_x as NO_2. Vehicles equipped with particle filters have also increased and certain types of particle filters also increase the directly emitted NO_2.

3. Other reasons may be differences in meteorology between 2007 and 2008 and minor changes in model approach and emission data.

Moreover, the number of streets exceeding the limit value plus margin of tolerance is very sensitive to small changes in concentrations as can be seen from Figure 3.3.

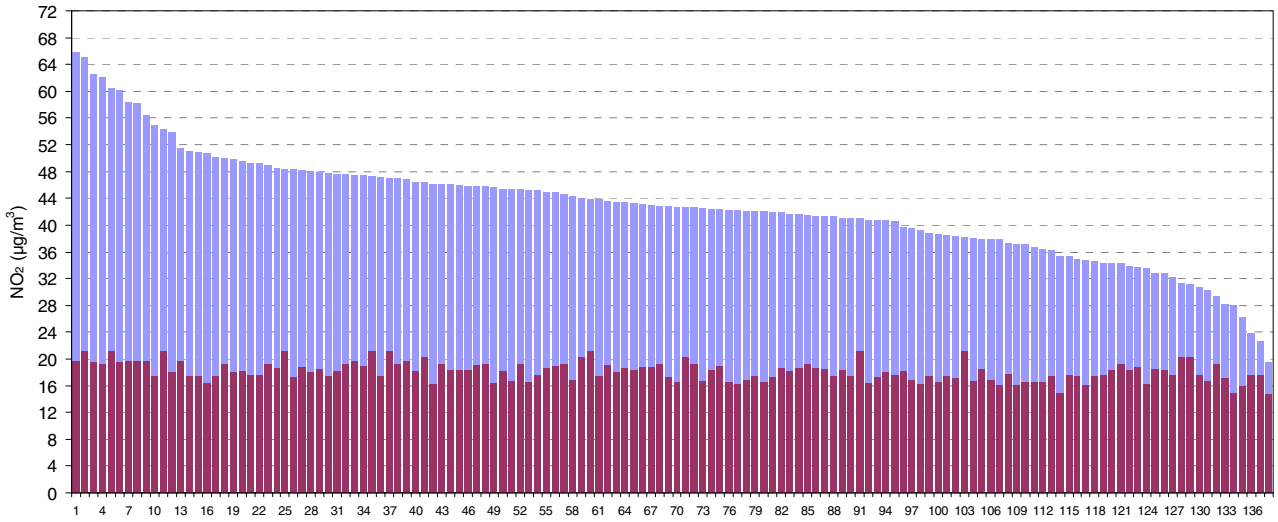

Figure 3.3 Annual mean concentrations of NO_2 in 2008 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background (dark red colour) is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration. The names of the streets can be seen in Table 3.5.

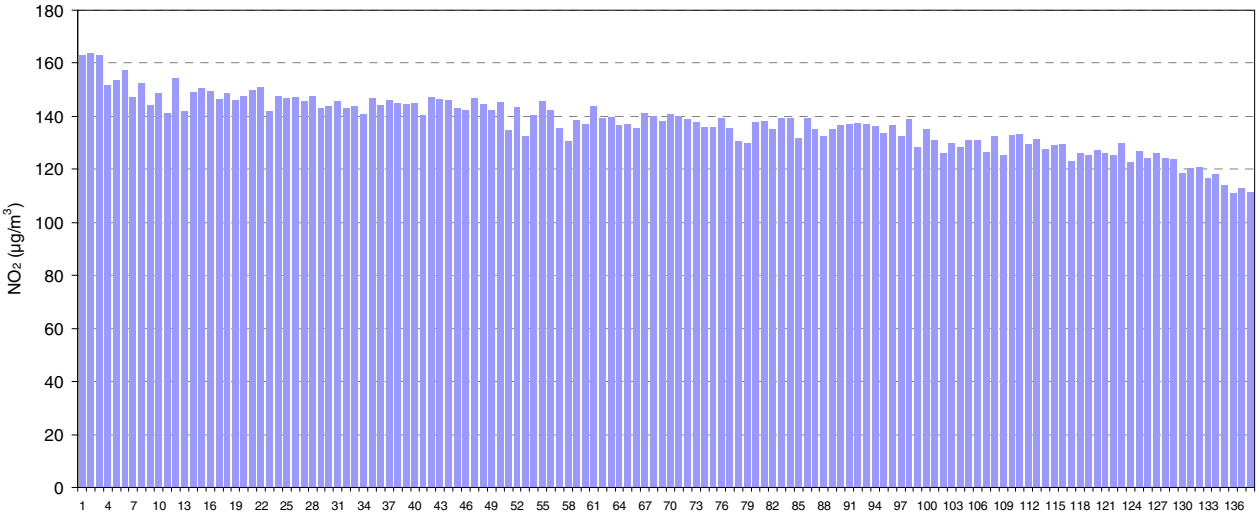

Figure 3.4 The 19th highest concentration of NO_2 in 2008 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration. The streets are sorted as in Figure 3.3. The names of the streets can be seen in Table 3.5.

The streets where the limit value plus margin of tolerance were exceeded all have a daily traffic intensity of more than 13.000 vehicles per day. However, it is not only the traffic intensity which determines the concentration of NO_2. Also the width of the streets, the height of the

surrounding buildings and the share of heavy-duty vehicles have large impact on the concentration of NO_2 in the streets.

The limit value plus margin of tolerance for the 19th highest concentration is not exceeded at any of the selected streets (Figure 3.4).

The names of the 138 streets are given in Table 3.5 and the locations of the streets together with the annual NO_2 concentration levels are shown in Figure 3.5. It is seen that the spatial distribution of the exceedances of the limit value plus margin of tolerance is not just concentrated to a few arterials but located throughout the city.

Table 3.5 Number and names for the streets that are shown in Figure 3.3, 3.4 and 3.5. The streets are numbered (1-138) according to NO_2 levels in 2008 (1 = highest, 138 = lowest). The numbers in parenthesis refer to different segments of the same street that has more than one model calculation.

Number	Street name
1	Nørre Søgade
2	H C Andersens Boulevard(3)
3	Lyngbyvej(2)
4	Ågade
5	H C Andersens Boulevard(2)
6	Lyngbyvej(3)
7	Gyldenløvesgade
8	Åboulevard(3)
9	Åboulevard(1)
10	Sydhavnsgade
11	H C Andersens Boulevard(1)
12	Tuborgvej(3)
13	Åboulevard(2)
14	Sallingvej(2)
15	Nordre Fasanvej(2)
16	Frederikssundsvej(8)
17	Jyllingevej(1)
18	Øster Søgade
19	Frederikssundsvej(3)
20	Vesterbrogade(3)
21	Østerbrogade(4)
22	Østerbrogade(3)
23	Borups Alle
24	Roligheds vej
25	Bernstorffsgade(2)
26	Toftegårds Allé(2)
27	Frederikssundsvej(1)
28	Tomsgårdsvej(1)
29	Sallingvej(1)
30	Nordre Fasanvej(1)
31	Gammel Kongevej(1)
32	Jagtvej(1)
33	H.C. Ørsteds Vej(1)
34	Vester Farimagsgade
35	Stormgade
36	Amagerfælledvej
37	Vester Voldgade
38	Nordre Fasanvej(3)
39	Rosenørns Alle
40	Gammel Kongevej(2)
41	Gothersgade(1)
42	Amagerbrogade(1)
43	Bredgade
44	Nordre Fasanvej(5)
45	Nørrebrogade
46	Folke Bernadottes Allé
47	Torvegade
48	Nordre Fasanvej(4)
49	Frederikssundsvej(5)
50	H.C. Ørsteds Vej(2)
51	Folehaven(1)
52	Tagensvej(3)
53	Gammel Køge Landevej(1)
54	Østerbrogade(1)
55	Falkoner Alle(2)
56	Vesterbrogade(2)
57	Tagensvej(4)
58	Grøndals Parkvej
59	Nørre Voldgade(1)
60	Bernstorffsgade(1)
61	Amagerbrogade(2)
62	Holmens Kanal
63	Tomsgårdsvej(2)
64	Bülowsvej(2)
65	Øster Voldgade(1)
66	Tagensvej(2)
67	Mimersgade
68	Jagtvej(4)
69	Søndre Fasanvej(2)
70	Østerbrogade(2)
71	Nørre Farimagsgade
72	Jagtvej(2)
73	Søndre Fasanvej(1)
74	Hillerødgade(3)
75	Vesterbrogade(1)
76	Frederikssundsvej(2)
77	Englandsvej(1)
78	P Knudsens Gade(2)
79	P Knudsens Gade(1)
80	Strandvejen(1)
81	Toftegårds Allé(1)
82	Bülowsvej(1)
83	Vesterfælledvej
84	Falkoner Alle(1)
85	Jagtvej(3)
86	Falkoner Alle(3)
87	Rebildvej
88	Smallegade
89	Dag Hammarskjølds Allé
90	Frederikssundsvej(6)
91	Hammerichsgade
92	Frederikssundsvej(7)
93	Jyllingevej(2)
94	Hareskovvej
95	Tagensvej(1)
96	Alhambravej
97	Peter Bangs Vej(2)
98	Frederiksborgvej(1)
99	Slotsherrensvej(2)
100	Frederiksborgvej(2)
101	Amager Boulevard
102	Folehaven(2)
103	Tietgensgade
104	Roskildevej(2)
105	Godthåbsvej(2)
106	Peter Bangs Vej(1)
107	Ålholmvej(2)
108	Istedgade
109	Vigerslevvej(2)
110	Strandvejen(3)
111	Strandvejen(2)
112	Slotsherrensvej(1)
113	Frederikssundsvej(4)
114	Amagerbrogade(3)
115	Tuborgvej(2)
116	Bellahøjvej
117	Vigerslevvej(1)
118	Hulgårdsvej(2)
119	Ålholmvej(1)
120	Godthåbsvej(3)
121	Hulgårdsvej(1)
122	Hillerødgade(4)
123	Hillerødgade(1)
124	Røde Mellemvej(1)
125	Godthåbsvej(1)
126	Tagensvej(5)
127	Tuborgvej(1)
128	Øster Voldgade(2)
129	Nørre Voldgade(2)
130	Kalvebod Brygge
131	Roskildevej(1)
132	Fredensgade
133	Gammel Køge Landevej(2)
134	Røde Mellemvej(2)
135	Englandsvej(2)
136	Vigerslev Allé
137	Artillerivej
138	Strandvænget(2)

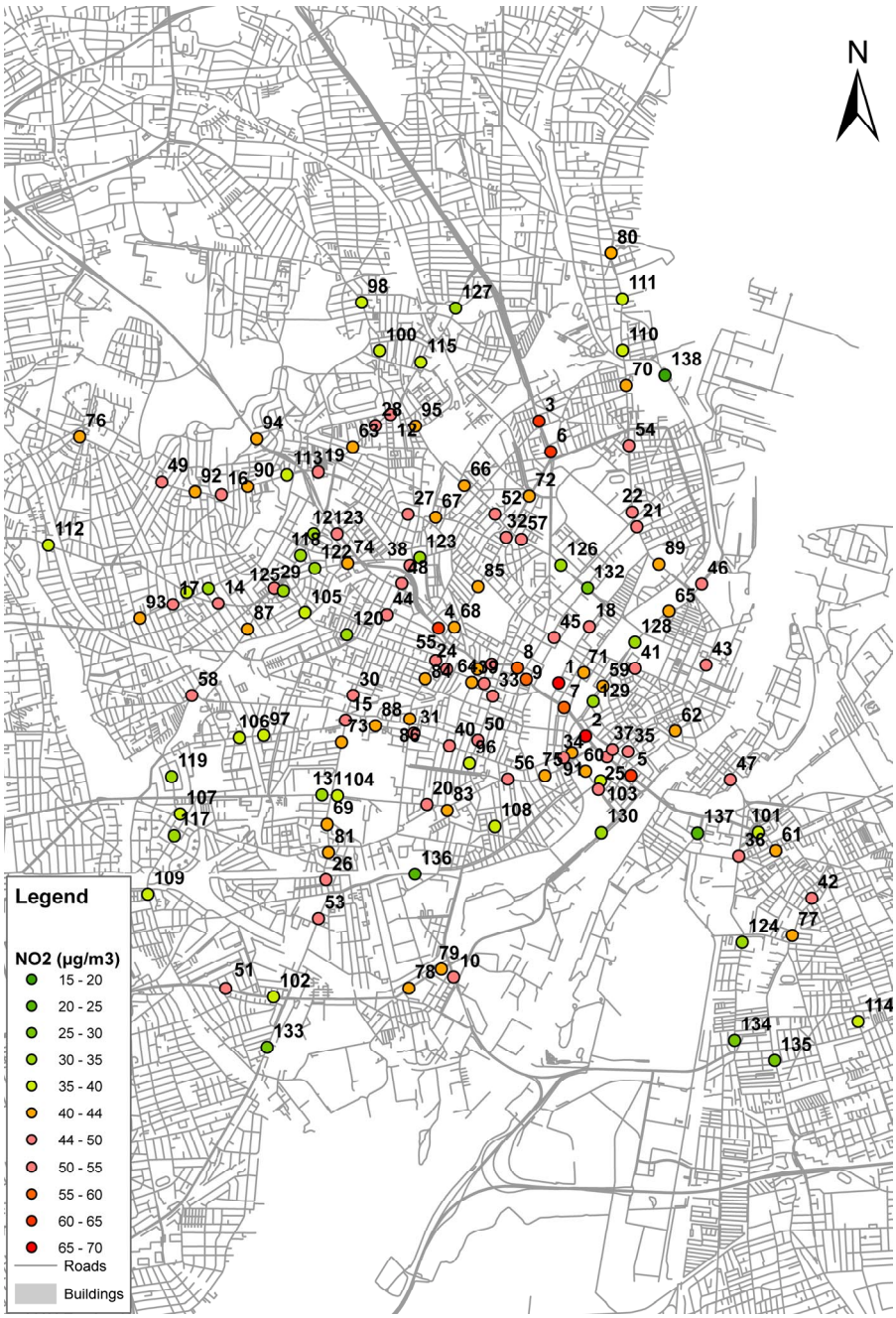

Figure 3.5 Map showing the locations of the selected streets in Copenhagen and the annual mean concentrations of NO_2 for 2008. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration. The names and numbers for the streets are shown in Table 3.5.

3.4.2 Model calculations for Aalborg

For Aalborg the model calculations show that the limit value plus margin of tolerance for the annual mean concentration in 2008 was exceeded in 4 out of the 32 selected streets compared to 3 times in 2007 (Figure 3.6 and Figure 3.8). The reasons for this increase between 2007 and 2008 are the same as for Copenhagen (see Chapter 3.4.1).

The limit value plus margin of tolerance for the 19th highest concentration is not exceeded at any of the selected streets (Figure 3.7).

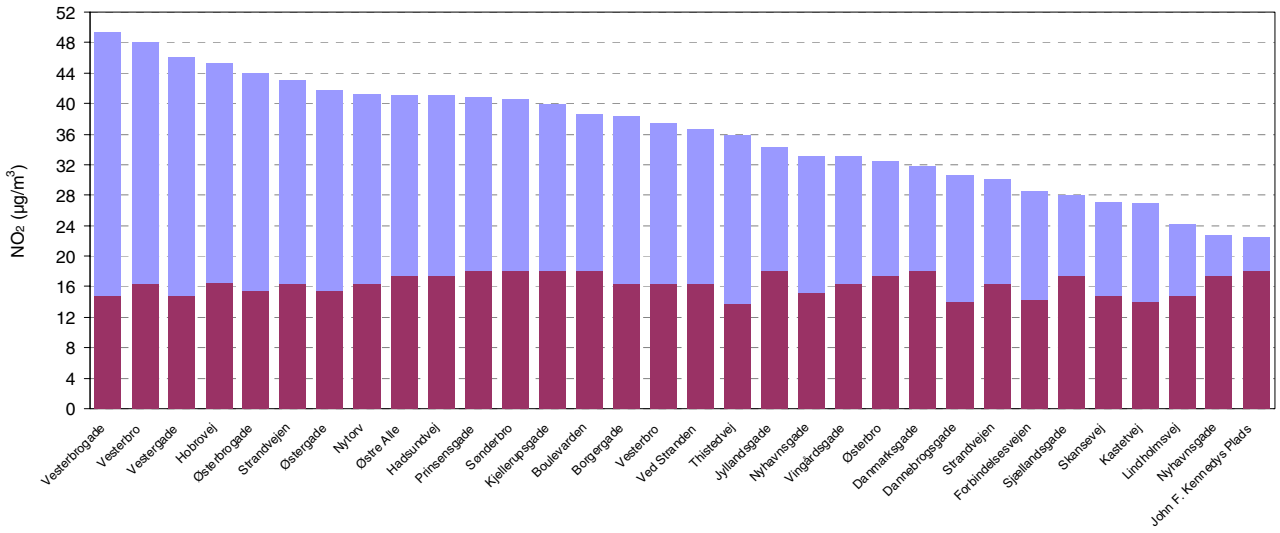

Figure 3.6 Annual mean concentrations of NO_2 in 2008 for 32 streets in Aalborg. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background (dark red colour) is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration.

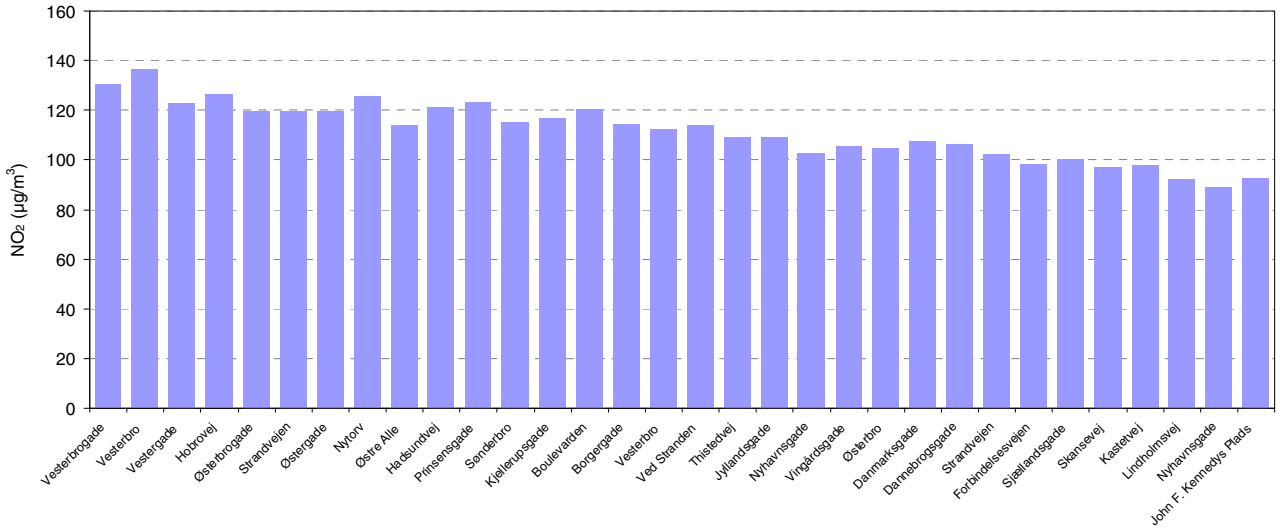

Figure 3.7 The 19th highest concentration of NO_2 in 2008 for 32 streets in Aalborg. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration. The streets are sorted as in Figure 3.6.

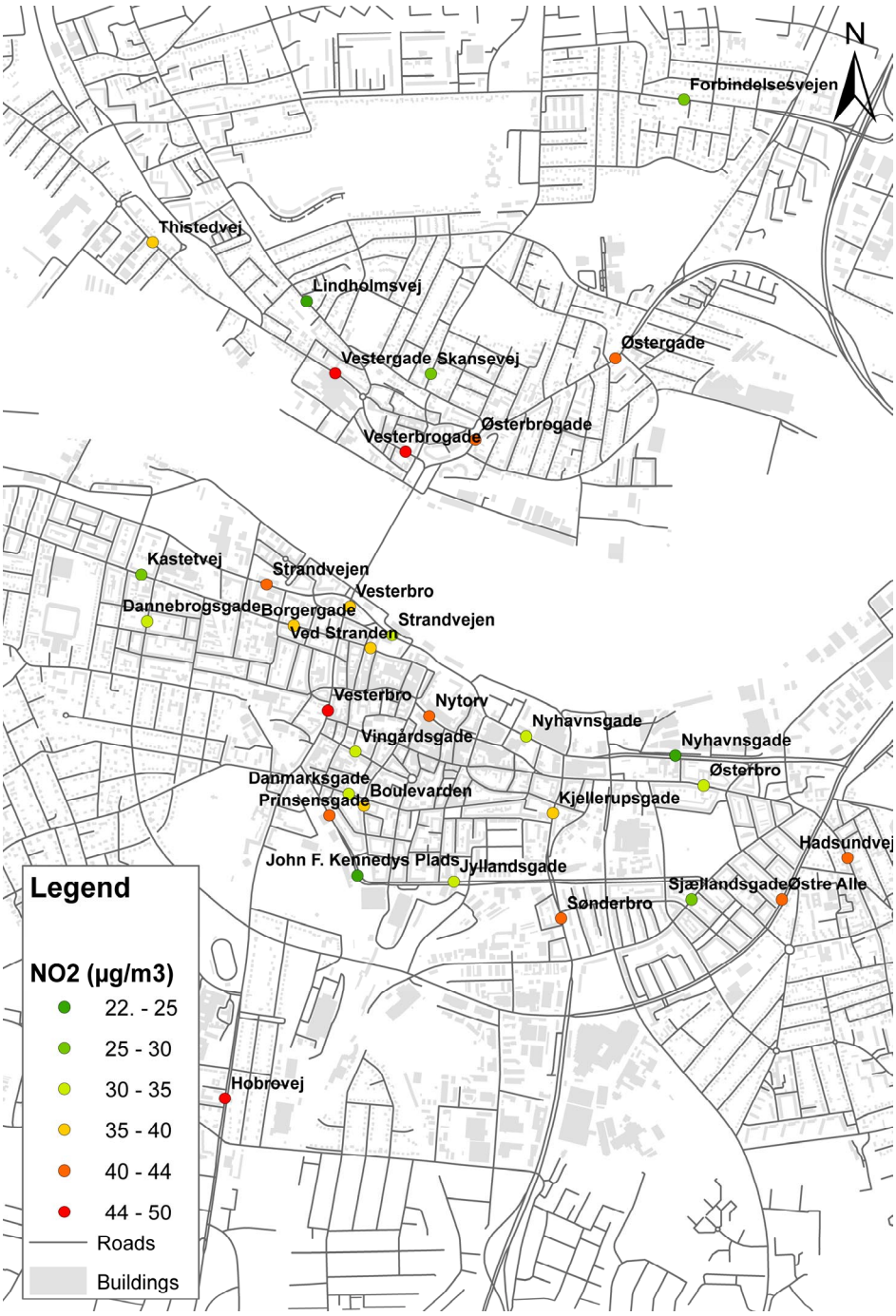

Figure 3.8 Map showing the location of the selected streets in Aalborg and the annual mean concentrations of NO_2 for 2008. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration.

3.4.3 Model calculations for protection of ecosystems

The limit value for protection of ecosystems is 30 µg/m³ NO_x calculated as NO_2 for the calendar year. The limit value is based on EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). The results from the model calculations show (Figure 3.9) that the annual mean concentrations of NO_x were below the limit value in 2008. The only exception from this is for Copenhagen; however, the limit value for protection of vegetation is only valid outside agglomerations.

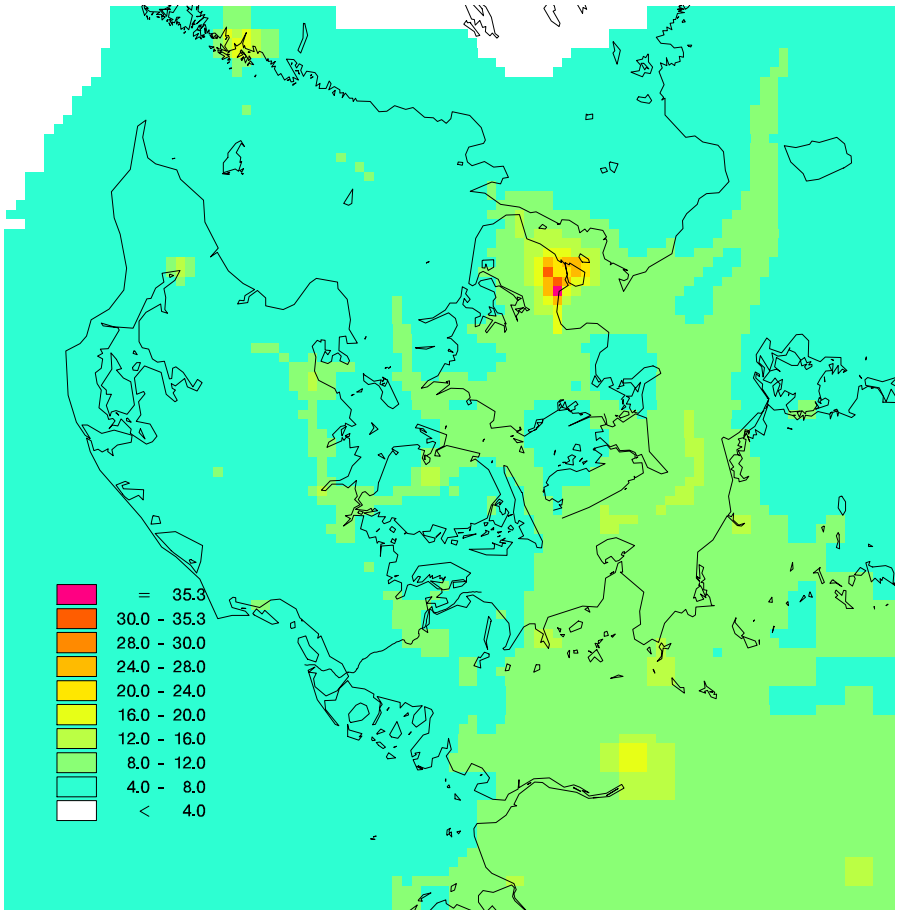

Figure 3.9 Annual mean concentrations of NO_x for 2008 calculated with DEHM given as µg/m³, when all NO_x is calculated as NO_2. The figure shows the average concentrations for the 5.6 km x 5.6 km grid cells used in the model.

4 Ozone

4.1 Annual statistics

Table 4.1 Ozone (O_3) 2008. All parameters are calculated using one-hour average values. The eight hour values are calculated as a moving average based on hourly measurements. For the "26. highest 8 hour" value is used the highest daily 8 hour average values calculated as described in the EU Directive 2002/3/EC.

Unit: µg/m^3	Number of results	Average	Median	Max. 8 hours	26. highest 8 hour	Max. 1 hour	AOT40 µg/m^3.h
Urban Background:							
Copenhagen/1259	7984	51	51	130	101	140	8455
Århus/6159	8246	48	49	120	96	135	7410
Odense/9159	8153	53	54	128	104	139	11026
Aalborg/8158	8744	54	56	135	101	139	9050
Rural							
Lille Valby/2090	8705	55	55	131	96	137	12378
Keldsnor/9055	8642	58	58	126	102	137	9514
Traffic							
Copenhagen/1257	8722	39	38	106	79	115	1027
Copenhagen/1103	8218	33	31	107	75	122	470
Target value	>7884	-	-	-	120	-	18 000
Long term objective	>7884	-	-	120	-	-	6 000

The target values and long term objectives are given in the EU Council Directive (EC, 2002) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

Number of information to the public due to exceedance of the information threshold (180 µg/m^3) in 2008: 0.

Number of information to the public due to exceedance of the alert threshold (240 µg/m^3) in 2008: 0.

4.2 Trends

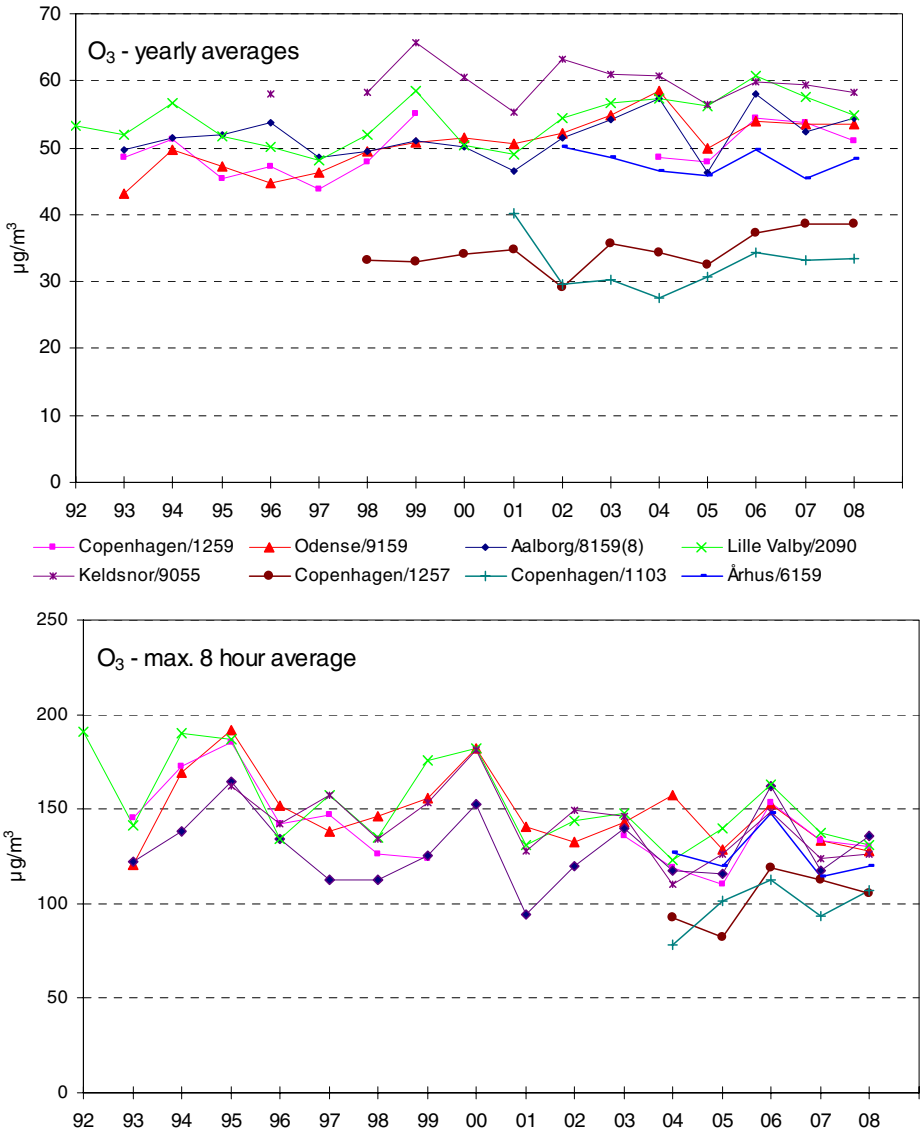

Figure 4.1 Annual average values and the max. 8 hour average value. The latter is calculated as hourly 8 hour running averages according to the provisions in the EU Council Directive (EC, 2002). Previous results from Copenhagen/1103 can be found at the Website of the Copenhagen Environmental Protection Agency (www. Miljoe.kk.dk).

4.3 Results from model calculations

The target value for protection of human health is that the running 8 hour mean concentration of ozone must not exceed 120 µg/m^3 more than 25 times a calendar year. The long term objectives are that the running 8 hour mean concentration of ozone must not exceed 120 µg/m^3. The target value and long term objective are given in the EU Council Directive (EC, 2002) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). Results from the model calculations for 2008 show that the target value was not exceeded (figure 4.3). However, the long term objective was exceeded at several places in Denmark; mainly in the coastal areas (Figure 4.4).

According to the directive (EC, 2002) the public has to be informed if the one hour mean concentration exceed the information threshold of 180 µg/m^3. Based on measurements this threshold was not exceeded in 2008. The model calculations show also that the one hour mean concentration did not exceed 180 µg/m^3 in 2008 (Figure 4.5). However, the model results are 10-20% lower than the measurements. The reason for this discrepancy is most likely that the model does not include emissions from wild fires. Large wild fires are known to increase episodic ozone concentrations. Work has been initiated to include emissions from wild fires in the model. Inclusion of emissions of wild fires in the model calculations may also increase the area where the long term objective for ozone was exceeded in 2008.

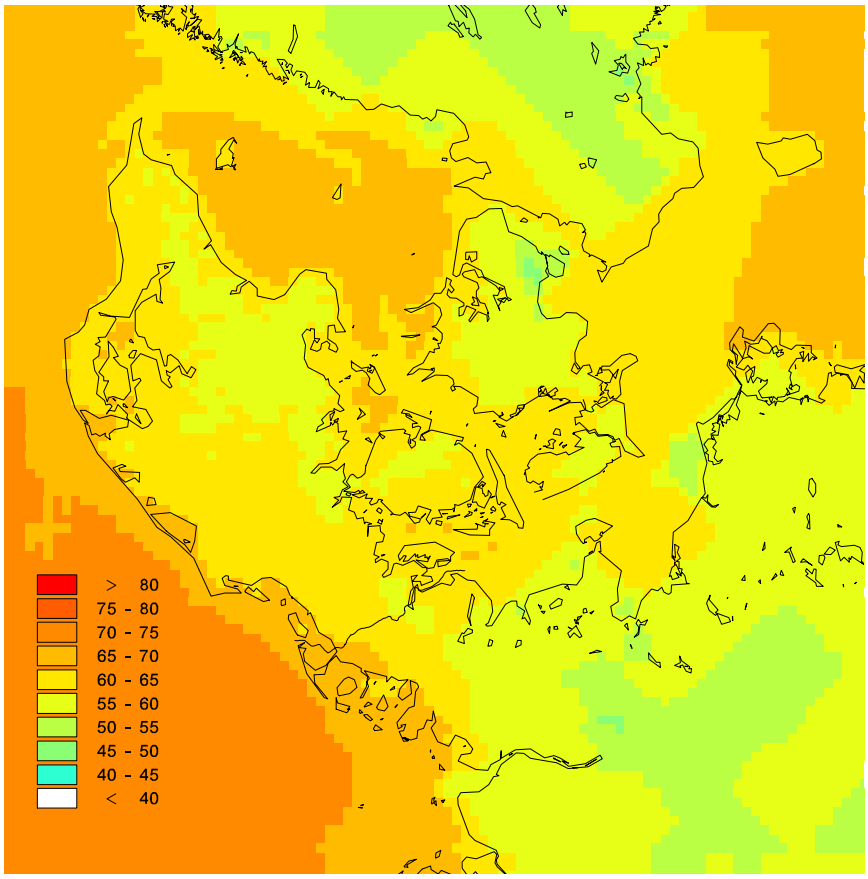

Figure 4.2 Annual mean concentrations of O_3 (µg/m^3) for 2008 calculated using DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model.

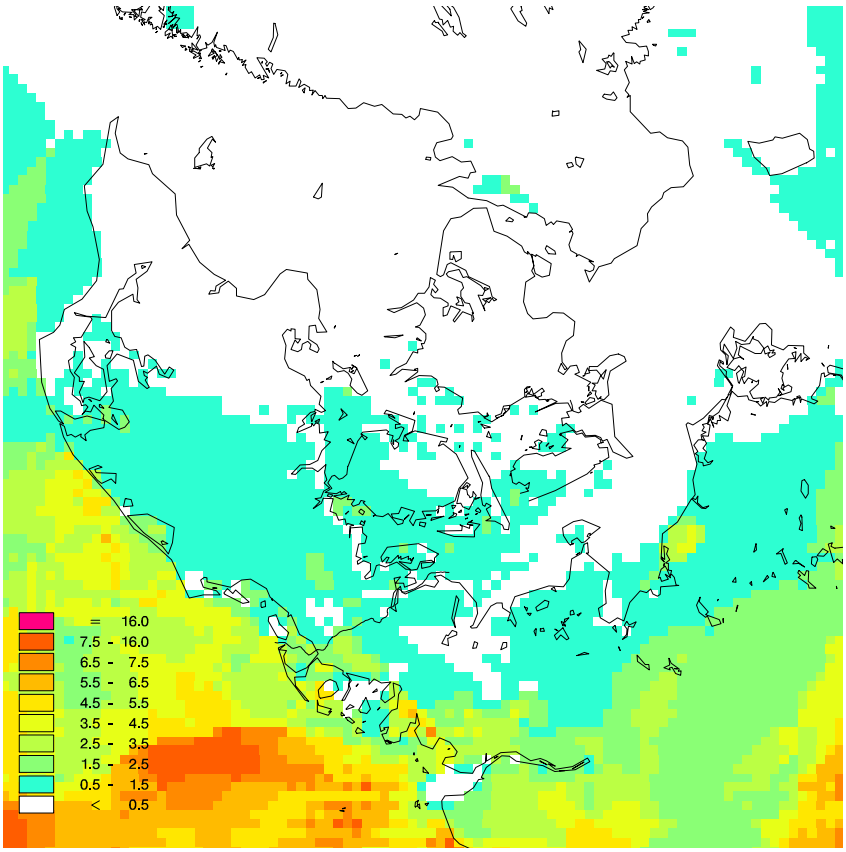

Figure 4.3 Number of exceedances of 120 µg/m^3 for 8-hour running mean concentrations of ozone in 2008. The calculations were carried out using DEHM.

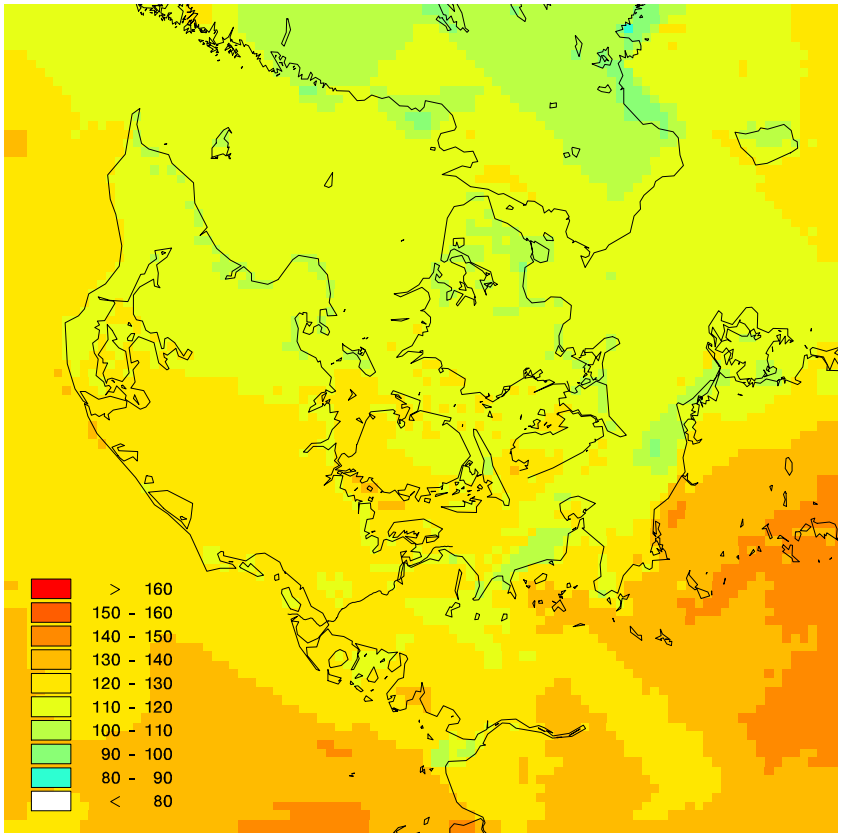

Figure 4.4 Maximum 8 hour running mean concentration (µg/m^3) of ozone in 2008 calculated using DEHM.

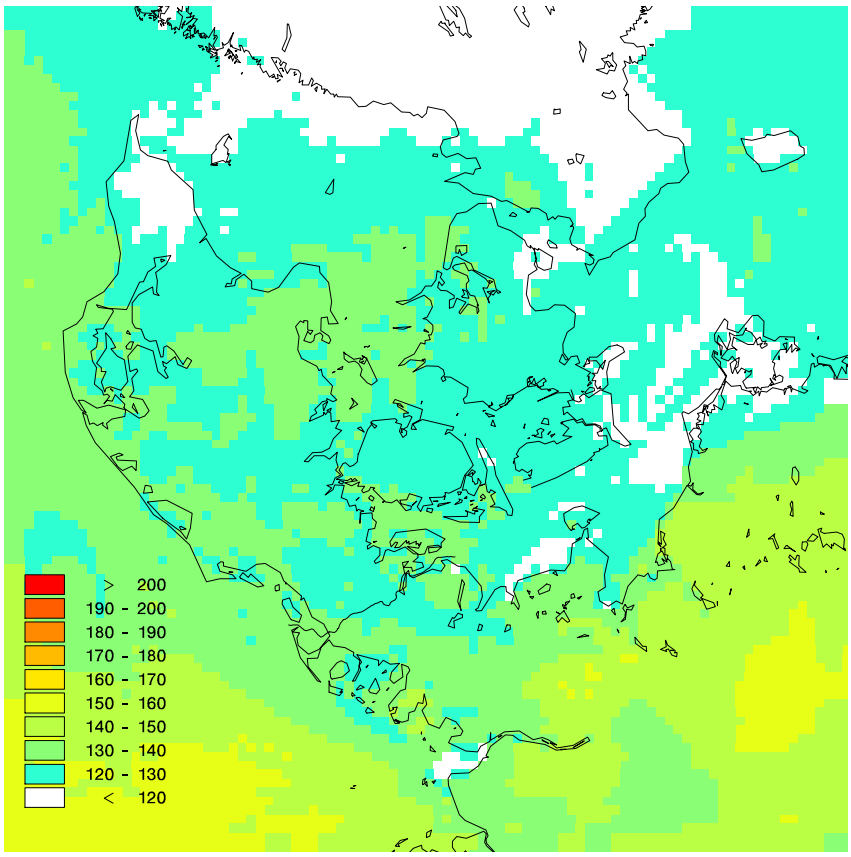

Figure 4.5 Maximum one hour mean concentration of ozone (µg/m3) in 2008 calculated using DEHM.

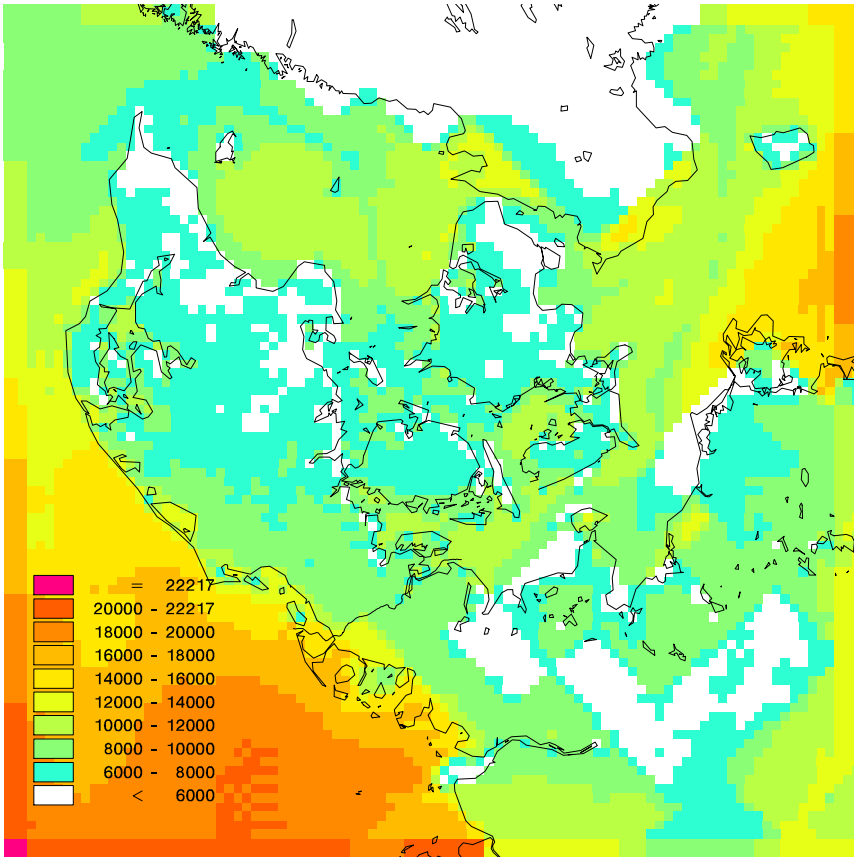

Figure 4.6 AOT40 ((µg/m^3)·h) calculated for 2008 using DEHM.

AOT40 (in units of (µg/m^3)·h) is the sum of the hourly difference between values above 80 µg/m^3 (=40 ppbv) and 80 µg/m^3 measured during the time from 8:00 to 20:00 in the period from May to July. The target values and long term objectives for protection of vegetation is 18000 and 6000 µg/m^3·h, respectively. The target values and long term objectives are given in the EU Council Directive (EC, 2002) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). The results from the model calculations for 2008 using DEHM (Figure 4.6) show that AOT40 was below the target value except for a very few coastal places. However, the long term objective was exceeded for more than half of the country.

5 Carbon monoxide

5.1 Annual statistics

Table 5.1 Annual statistics for carbon monoxide (CO) in 2008. All parameters are calculated with hourly average. The 8-hour values are calculated as a moving average based on hourly results.

Unit: µg/m^3	Number	Average	Median	98-percentile	99.9-percentile	Max. 8-hours	Max hour
Traffic:							
Copenhagen/1257	8767	547	471	1414	2572	2531	6520
Copenhagen/1103	5977	489	438	1211	1911	1424	3348
Århus/6153	6854	363	318	881	1645	1288	2012
Odense/9155	7666	457	344	1459	3270	2980	3590
Aalborg/8151	8692	503	417	1340	2051	1618	2250
Urban Background:							
Copenhagen/1259	7981	250	230	494	826	693	1240
Rural							
Lille Valby/2090	5662	255	228	586	2447	2392	2480
Limit value	-	-	-	-	-	10 000	-
Guideline values	-	-	-	-	-	10 000	30 000

The limit value is based on EU Council Directive (EC, 2000) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The guideline values are proposed in WHO, 2000. (Air Quality Guidelines for Europe, Second Edition, WHO Regional Publications, European Series, No. 91, Copenhagen 2000).

5.2 Trends

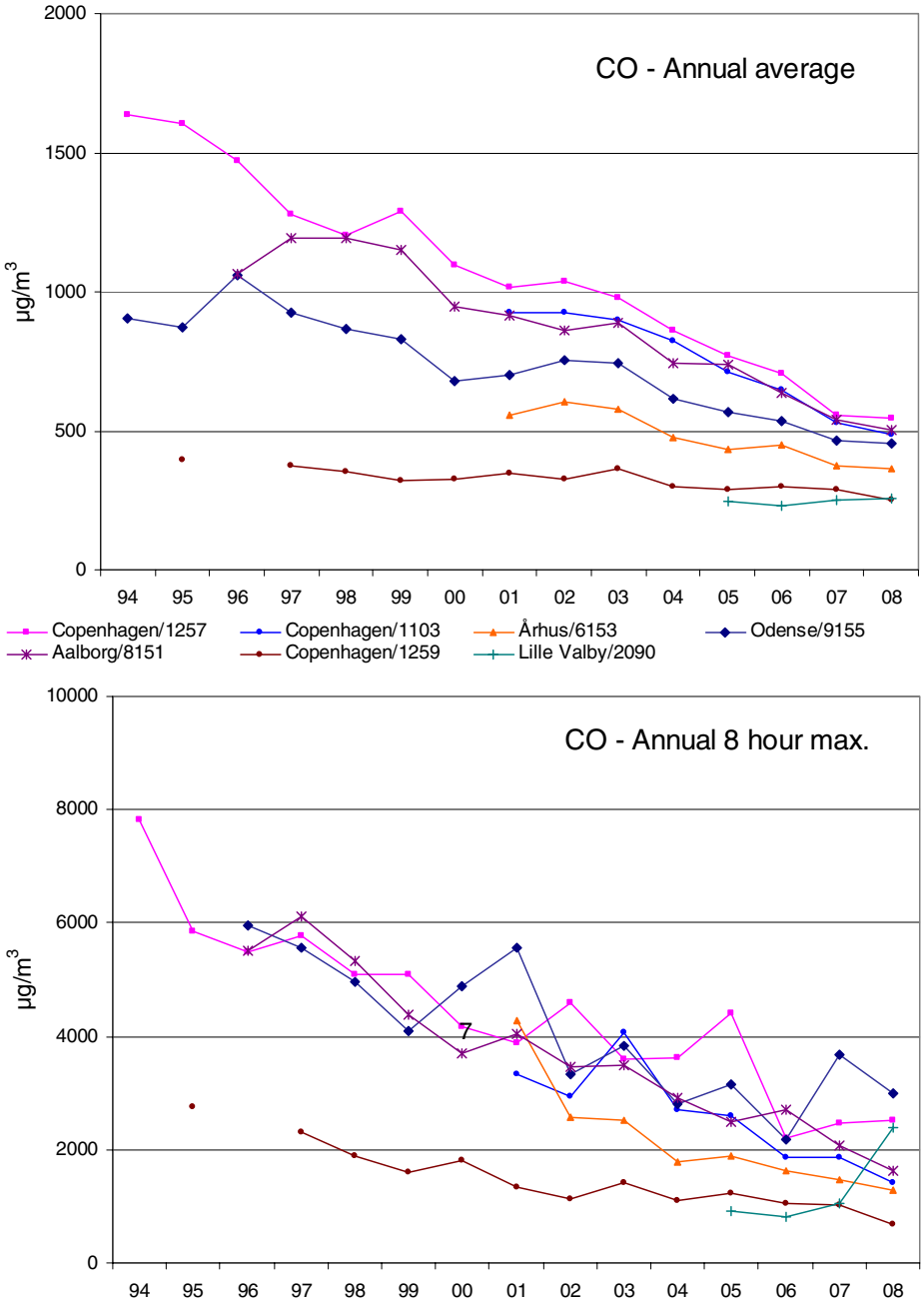

Figure 5.1 Annual average values and highest 8-hour value calculated based on an hourly moving average. Previous results from Copenhagen/1103 can be found at the website of the Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk).

6 Benzene and Toluene

The measurement method for Benzene and Toluene is revised. The level has been decreasing during the last years and the concentration are well below the EU limit value. There has been some technical problems with equipment used up to now. Thus the use of passive sampling seems to be sufficient to comply with demands set by the Directive.

The measurements started effectively in August 2008 at the two street stations in Copenhagen.

6.1 Annual statistics

Table 6.1 Annual statistics for Benzene in 2008. All values are calculated based on weekly averages. The life time risk level is defined as the concentration that through a lifelong exposure is estimated to give an increase in risk of $1:10^5$ for developing cancer. Note that the measurements are only from the second half of 2008.

Unit: µg/m^3	Number of results	Average
Copenhagen/1103	23	1.4
Copenhagen/1257	26	1.6
Life time risk level at $1:10^5$		1.7

The limit value is based on EU Council Directive (EC, 2000) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

Table 6.2 Annual statistics for Toluene in 2008. The max. 7 days is the maximum value for the weekly measurements (WHO, 2000). Note that the measurements are only from the second half of 2008.

Unit: µg/m^3	Number of results	Average	Max. 7 days
Copenhagen/1103	23	4.4	6.6
Copenhagen/1257	26	5.5	8.4
Guideline value	-	-	260

The guideline and lifetime risk level are established by WHO (WHO, 2000).

6.2 Trends

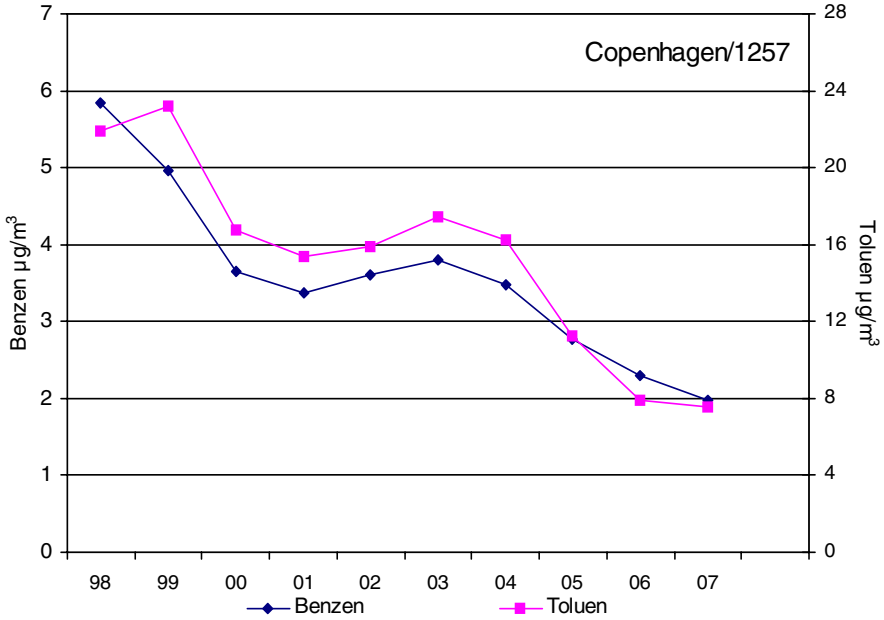

Figure 6.1 Annual average for benzene and toluene measured at Copenhagen/1257. Values from 2008 are incomplete and not included on the graph.

7 Particles (TSP, PM_{10} and $PM_{2.5}$)

7.1 PM measurements

The limit values are based on the EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

The SM200 sampler manufactured by OPSIS, Sweden, has been used in Denmark to measure PM_{10} in accordance with the EU Directive (EC, 1999). The method has now been extended to include $PM_{2.5}$. The sampler provides the possibility for online diurnal measurements of PM in combination with sampling of PM on filters. The filters can later be used for weighing and chemical analysis. The online measurements of PM are determined immediately after the diurnal sampling period by means of absorption of β-rays in the particles. This option provides the possibility of presenting "on-line" results via internet.

Results indicate that the β-ray results from the SM200 sampler comply better with the reference method for PM_{10} given in the Directive, than the results from weighing of the filters (Harrison, 2006). For this reason we have decided from 2006 and onwards to report results from the β-method. Previously, results from weighing of the filters were reported.

The results from the two methods differ slightly. From 2002 to 2005, where comprehensive data sets are available, it is shown that the β-method in average yields results that are 1.08 times the weighing for the yearly average and 1.09 times the weighing for the 39th highest concentration.

7.2 Annual statistics

At all stations PM_{10} and/or $PM_{2.5}$ were collected continuously on filters on diurnal basis for subsequent β-absorption measurement shortly after exposure (Table 7.1) using SM200-monitors. Subsequently the particle samples were analysed in the laboratory. Additionally PM is measured at the stations in the Copenhagen area using a TEOM (Tapered-element oscillating microbalance) instrument. The TEOM measurements are performed with a time resolution of 30 minutes (Table 7.3). During sampling the particles are heated to 50°C. At that temperature some of the volatile compounds may evaporate (mainly secondary aerosols). The loss will depend of the actual composition of the aerosols. The European Commission has accepted that TEOM measurements for PM_{10} can be used in relation to EU limit values if the measured values are multiplied with a factor 1.3. However, the correction factor depends on the specific measurement site and measurements of PM_{10} using TEOM and a correction factor of 1.3 may therefore have high uncertainty.

Due to technical problems with the SM200-monitors only 235 diurnal values were measured at the station at Copenhagen/1103 (H. C. Andersens Boulevard) due to lack of measurements during autum. The annual average based on these measurements (42 µg/m^3) is therefore not representative for the full year. However, based on the TEOM measurements of PM10 at H.C. Andersens Boulevard and the measurements at Copenhagen/1259 (H.C. Ørsted Institute) it is possible to calculate an estimate of PM10 for the lacking data during autumn. This estimate is described in detail in Appendix 2. Based on both the measurements with SM200 and the estimates an annual average of 39 µg/m^3 is calculated based on 288 diurnal values. Hence, this value is more representative for the annual average of 2008 than using the SM200 measurements alone.

Table 7.1 Annual statistics for PM_{10} in 2008. All parameters are calculated as daily averages.

Unit µg/m^3	Number of results	Average	36.highest result	90 percentile	95 percentile	8.highest result	Max. day
Traffic							
Copenhagen/1257	346	30	47	47	53	58	66
Copenhagen/1103 **)	288	39	59*)	61	71	80	126
Århus/6153	342	27	40	40	49	56	83
Odense/9155	282	31	46	48	55	60	75
Urban background							
Copenhagen/1259	284	21	30	32	37	41	55
Rural							
Lille Valby/2090	285	18	27	28	35	38	58
Keldsnor/9055	363	19	31	31	39	43	65
Limit values (2005)	>329	40	50				

*) Limit value exceeded.

**) Based on both SM200 and the estimate described in Appendix 2.

Table 7.2 Annual statistics for $PM_{2.5}$ in 2008. All parameters are calculated as daily averages. The limit values shall be met in 2015.

Unit µg/m^3	Number of results	Average	36.highest result	90 percentile	95 percentile	8.highest result	Max. day
Traffic							
Copenhagen/1103	332	22	32	33	36	41	48
Århus/6153	331	15	24	25	33	39	45
Aalborg/8151	313	18	29	29	34	40	51
Urban background							
Copenhagen/1259	169	13	-	-	-	-	-
Århus/6159	318	12	21	22	27	32	35
Aalborg/8158	332	16	25	26	32	38	46
Rural							
Lille Valby/2090	158	11	-	-	-	-	-
Limit value (2015) (proposed 2020)	>329	25(20)					

Table 7.3 Annual statistics for PM_{10} measured in 2008 using TEOM. The values are calculated based on daily averages.

Unit µg/m^3	Number of results	Average	36.highest result	90 percentile	Average × 1.3	36. highest × 1.3
Traffic						
Copenhagen/1103	185	26	35	39	33	45
Urban background						
Copenhagen/1259	154	13	-	-	17	-
Limit values	>329	-	-	-	40	50

Table 7.4 Annual statistics for $PM_{2.5}$ measured in 2008 using TEOM. The values are calculated based on daily averages.

Unit µg/m^3	Number of results	Average	36.highest result	90 percentile
Traffic				
Copenhagen/1257	52	-	-	-
Copenhagen/1103	340	13	19	19
Urban Background				
Copenhagen/1259	288	9	14	15
Rural				
Lille Valby/2090	336	8	12	13

7.3 Trends

Up till 2000 the particulate matter was measured as Total Suspended Particulate matter (TSP) corresponding to particles with a diameter up to around 25 µm. The exact cut-off depended strongly on the wind velocity. From 2001 PM_{10} measurements are started at all stations except Copenhagen/1103 where the TSP measurements were continued to the end of 2005. The TSP is on the average 30-80% higher than PM_{10} at the street stations, while the difference is less at urban background and rural sites.

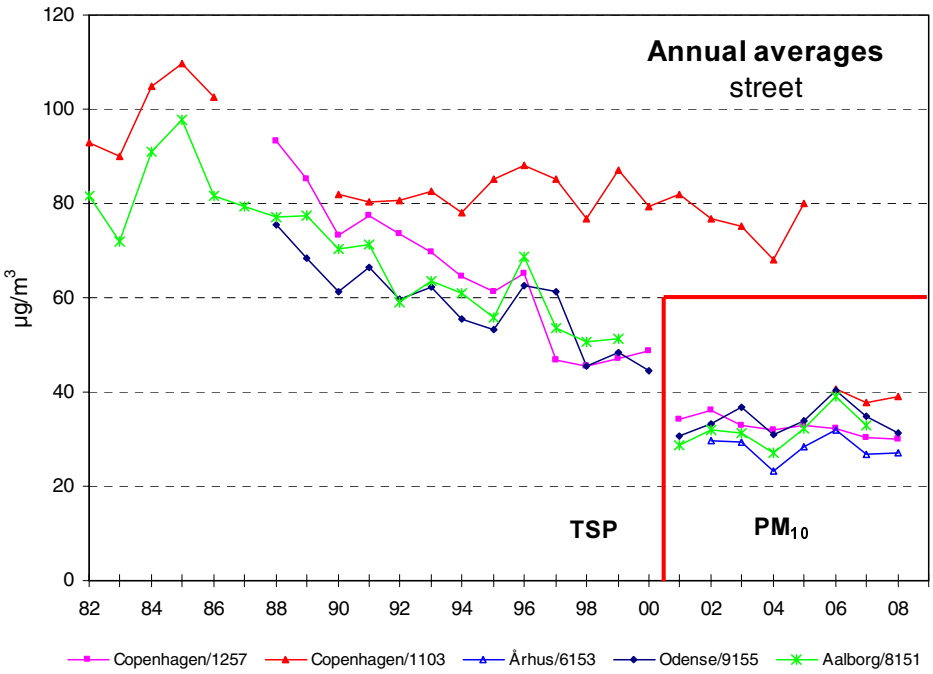

Figure 7.1 Annual averages for TSP and PM_{10} measured at street stations. Results from 2000 and earlier are for TSP, while later results are for PM_{10} – except for Copenhagen/1103, where TSP measurements were continued to the end of 2005. The PM_{10} results are shown in the area in the bottom right of the plot area. The change from gravimetric determination to use of β-measurements from 2006 gives rise to a 5-10% increase due to the shift of method. The value for PM_{10} at Copenhagen/1103 in 2008 is based on the measurements with SM200 and the estimate described above.

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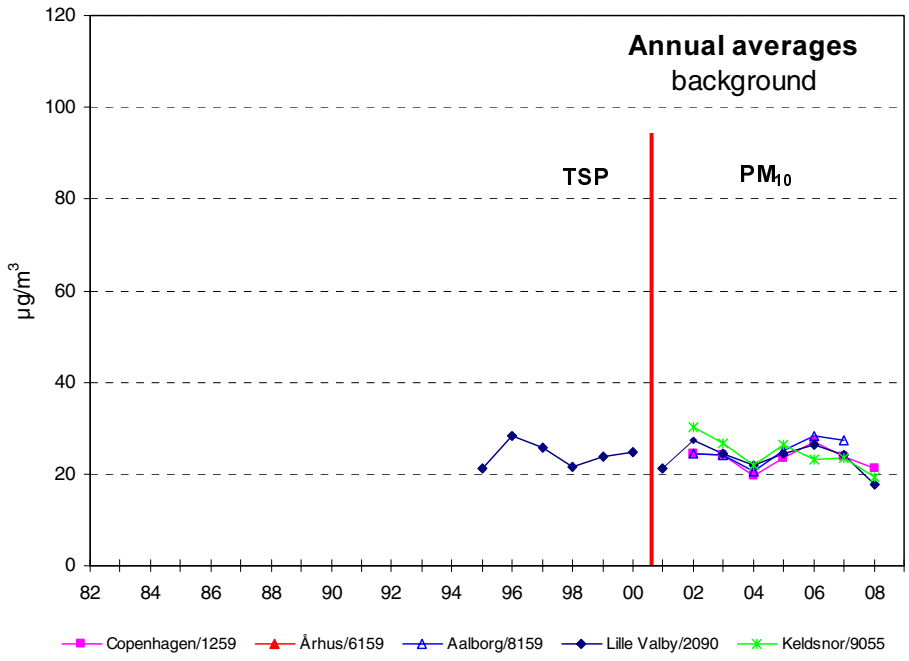

Figure 7.2 Annual averages for TSP and PM_{10} measured at urban background and rural stations. The change from gravimetric determination to use of β-measurements from 2006 gives rise to a 5-10% increase due to the shift of method.

8 Heavy Metals

8.1 Measurements of Heavy Metals

Collection of PM_{10} and $PM_{2.5}$ are performed on filters which can be used for chemical analysis. Selected filters are analysed by PIXE (Proton Induced X-ray Emission) for their content of elements. Results are presented below (Table 7.1).

The PIXE analysis provides the measurements obligatory for EU Council Directive 2004/107/EC (EC, 2005) for As, Cr and Ni. According to the Directive also Hg has to be measured, however, these measurements can be carried out in cooperation with neighbouring countries. As part of a bilateral agreement "Development of the mutual partnership on air pollution" between Denmark and Sweden it has been decided that the Swedish measurements at Röå (Table 7.2) can fulfil the Danish obligations on measurements of Hg. This agreement is based on the fact that the spatial variation of Hg is very low.

8.2 Annual statistics

Table 8.1 Annual statistics for Vanadium (V), Chromium (Cr), Manganese (Mn), Nickel (Ni), Cupper (Cu), Zink (Zn), Arsenic (As), Selenium (Se), Cadmium (Cd) and Lead (Pb) measured in PM_{10} dust during 2008 The lifetime risk level is defined as the concentration that through a lifelong exposure is estimated to give an excess risk of $1:10^5$ for developing cancer. The filters are occasionally contaminated with Cr, Ni, Cu and Zn. The outliers for these elements are excluded before calculation of averages. At urban background and rural stations the contamination with Cr still contributes with a significant amount to the average values.

Unit: ng/m^3	V	Cr	Mn	Ni	Cu	Zn	As	Se	Cd	Pb
PM10, Traffic										
Copenhagen/1257	3.4	5.7	13.3	3.4	56.0	33.4	0.5	0.4	< 0.1	5.3
Copenhagen/1103	5.3	14.0	46.3	5.0	101.1	77.2	0.6	0.4	< 0.1	8.7
Århus/6153	3.0	6.4	10.8	5.0	38.8	31.8	0.5	0.4	< 0.1	4.5
PM10, Urban background										
Copenhagen/1259	3.5	1.8	9.6	3.0	9.7	14.7	0.4	0.4	< 0.1	4.2
PM10, Rural										
Lille Valby/2090	2.1	1.1	3.6	1.5	6.4	< 1.2	0.5	0.4	< 0.1	4.3
PM2.5, Traffic										
Copenhagen/1103	2.9	1.8	5.2	2.0	14.2	17.6	0.4	0.3	< 0.1	3.9
Århus/6153	2.5	< 0.1	1.8	2.8	6.0	17.8	0.4	0.3	< 0.1	3.1
PM2.5, Urban background										
Copenhagen/1259	-	-	-	-	-	-	-	-	-	-
Århus/6159	2.6	< 0.1	1.2	2.7	3.3	< 1.1	0.4	0.3	< 0.1	3.0
PM2.5, Rural										
Lille Valby/2090	-	-	-	-	-	-	-	-	-	-
Target (limit) Values - EEC				20			6		5	(500)
Guideline value (WHO) *)	1000		150						5	
Life time risk level at $1:10^5$ (WHO) *)				25			6.6			

*) Target values for Ni, As and Cd are implemented through EU Council Directive 2004/107/EC (EC, 2005). A limit value for Pb is found in EU Council Directive 1999/30/EC (EC, 1999). The guidelines and life time risk for the carcinogenic metals are established by WHO (WHO, 2000).

Table 8.2 Annual statistics for Mercury 2008. Measured at Rööå in southern Sweden by the Swedish Environmental Research Institute (http://www.ivl.se/english/ivlstartpage/leftmenu/environmentaldata/ metalsinairandprecipitation.106.360a0d56117c51a2d30800064440.html).

Unit: ng/m3	Total Gas Hg (ng/m3)	Total Particles Hg (pg/m3)
Rööå (SEOOO14)	1.6	7.7

8.3 Trends

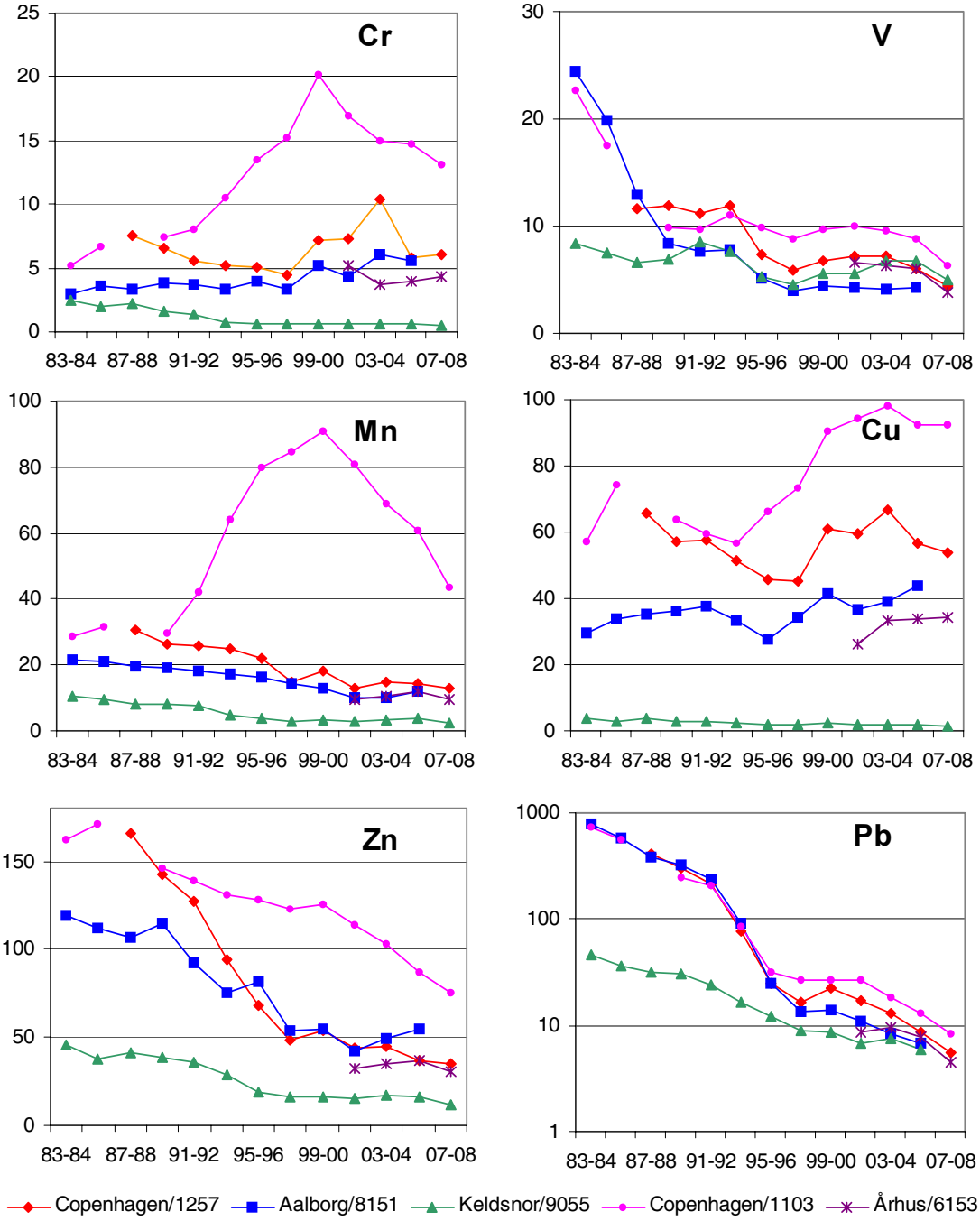

Figure 8.1 Biannual averages from selected stations for some heavy metals in particulate matter. Until 2000 in TSP and later in PM_{10} – except for Copenhagen/1103 where PM_{10} replaced TSP from the beginning of 2006. The heavy metals are usually found in fine particles, which make the TSP and the PM_{10} values comparable. The remarkable variations in the concentrations of especially Mn and to some extent Cr at Copenhagen/1103 may be caused by the use of slag from steel production for filling material in the bitumen at H. C. Andersens Boulevard. The increase in Cu (especially at Copenhagen/1103), which to a large extend comes from brake pads, reflects the increase in traffic volume. y-axis units are ng/m^3. (Note that the scale for Pb is logarithmic.)

9 Sulphur Compounds

9.1 Annual statistics

Table 9.1 Annual statistics for SO_2 in 2008. All parameters are calculated based on hourly averages. The detection limit for the monitors is a few µg/m^3, which makes the average and median values encumbered with high relative uncertainties.

Unit: µg/m3	Number of results	Average year	Average winter	Median	98-percentile	Max. Hour	4. highest day
Traffic							
Copenhagen/1103	8177	2.4	2.5	1.9	8.2	58	6
Aalborg/8151	8714	3.2	3.2	2.7	9.5	18	7
Limit values	>7884	20	20			350	125

The limit values are based on EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007).

Table 9.2 Annual averages for particulate sulphur (S) measured in PM_{10} in 2008. The sulphur containing particles are mainly present in sub-micron particles, which make the TSP and PM_{10} results comparable. Measurements are daily averages.

Unit: µg(S)/m3	Number of results	Average
Traffic		
Copenhagen/1257	363	0.65
Copenhagen/1103	243	0.83
Århus/6153	347	0.64
Urban background		
Copenhagen/1259	290	0.58
Rural		
Lille Valby/2090	334	0.54

9.2 Trends

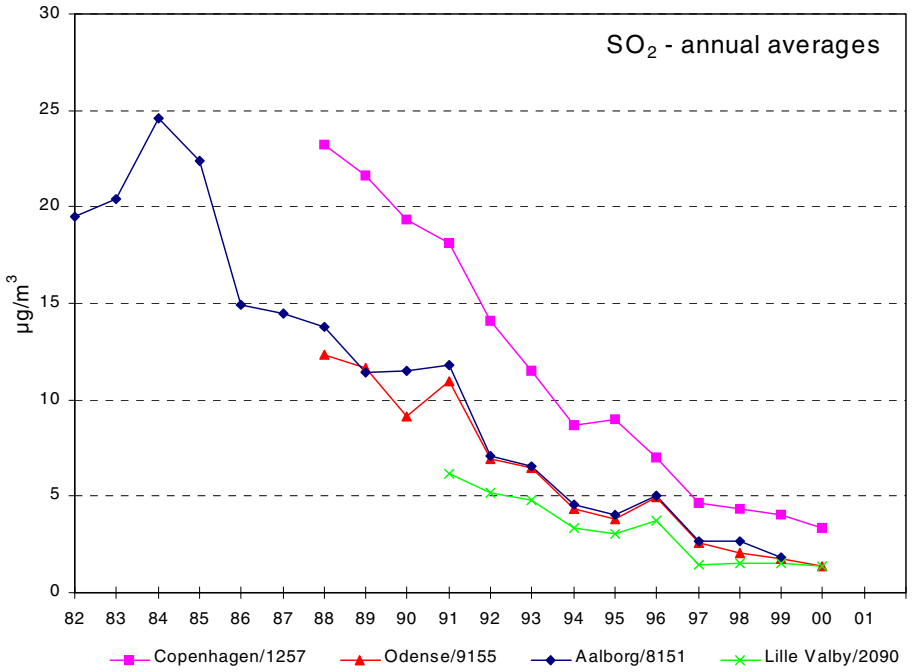

Figure 9.1 Annual averages for SO_2. The results are obtained using KOH impregnated filters for collection of SO_2. These measurements ceased in 2000 because the concentrations had become far below the limit and guideline values. Due to the low concentrations the trend curve is not continued after 2000. The aim with the measurements is to monitor episodic results.

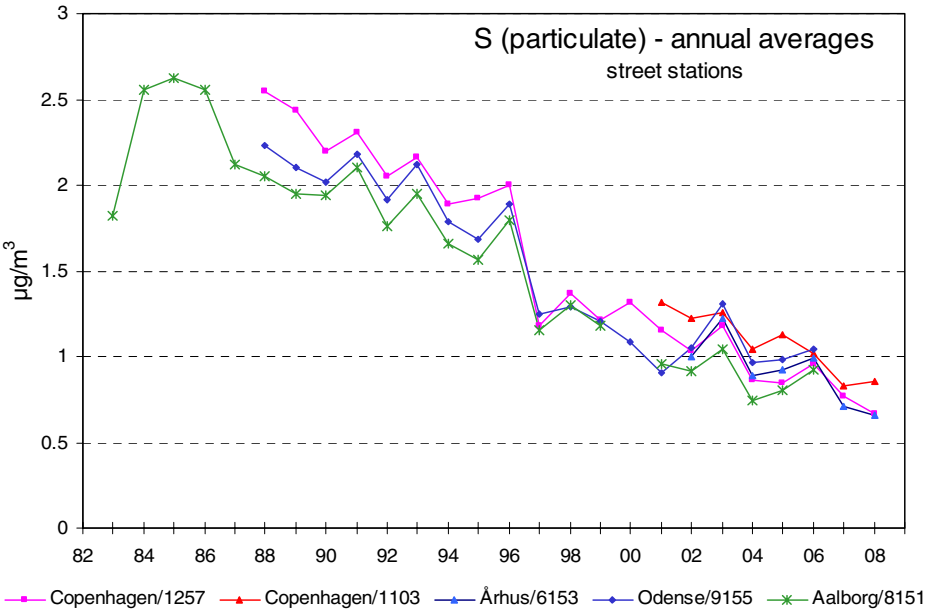

Figure 9.2 Annual averages for particulate sulphur at street stations. The particulate sulphur from 2000 and earlier is determined in TSP, and the 2001 results and later are for PM_{10} – except for Copenhagen/1103, where TSP measurements are continued. The sulphur containing particles are mainly present in sub-micron particles, which makes the TSP and PM_{10} results comparable.

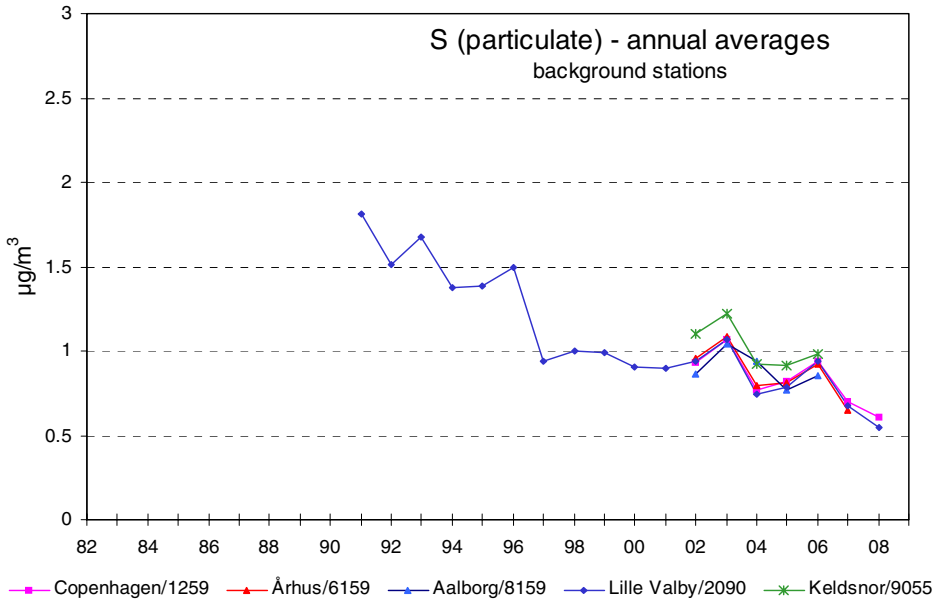

Figure 9.3 Annual averages for particulate sulphur at urban background and rural stations. The particulate sulphur from 2000 and earlier is determined in TSP and the 2001 results and later are in $PM_{10.}$ The sulphur containing particles are mainly present in sub-micron particles, which makes the TSP and PM_{10} results comparable.

9.3 Results from model calculations

The limit value for protection of ecosystems is 20 µg/m^3 SO_2 calculated both for the calendar year and winter period (1st October to 31st March). The limit value is based on EU Council Directive (EC, 1999) and implemented through a national Statutory Order from the Ministry of Environment (Miljøministeriet 2007). The results from the model calculations using DEHM show that the annual and winter mean concentrations of SO_2 in 2008 (Figure 9.4 and 9.5) are below the limit value.

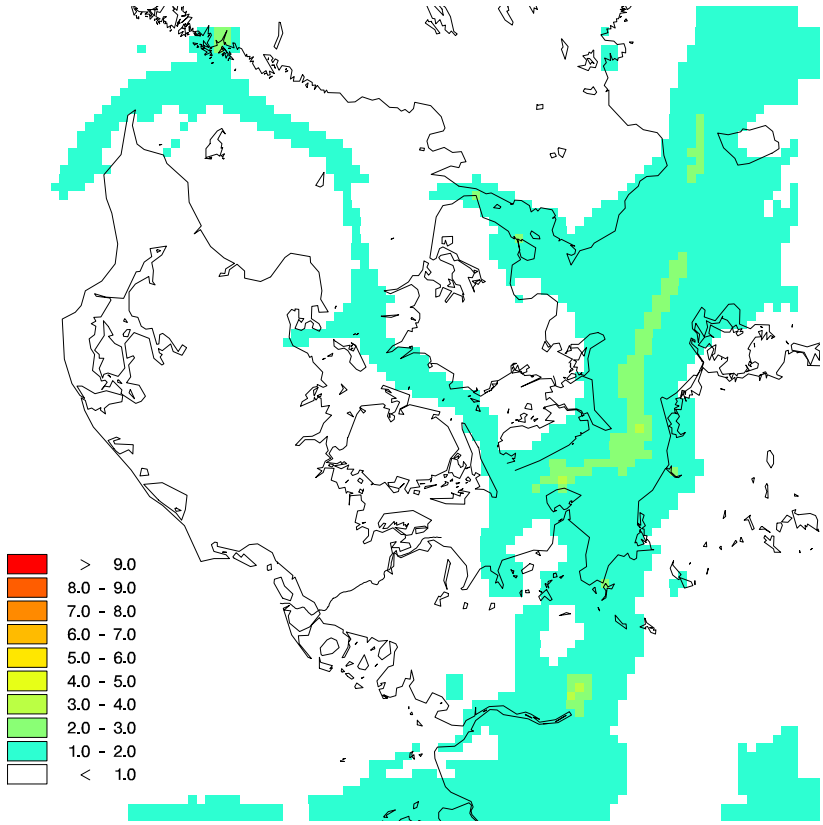

Figure 9.4 Annual mean concentrations of SO_2 (µg/m^3) for 2008 calculated with DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model. The higher concentrations calculated for the inner Danish waters are due to emissions from ships.

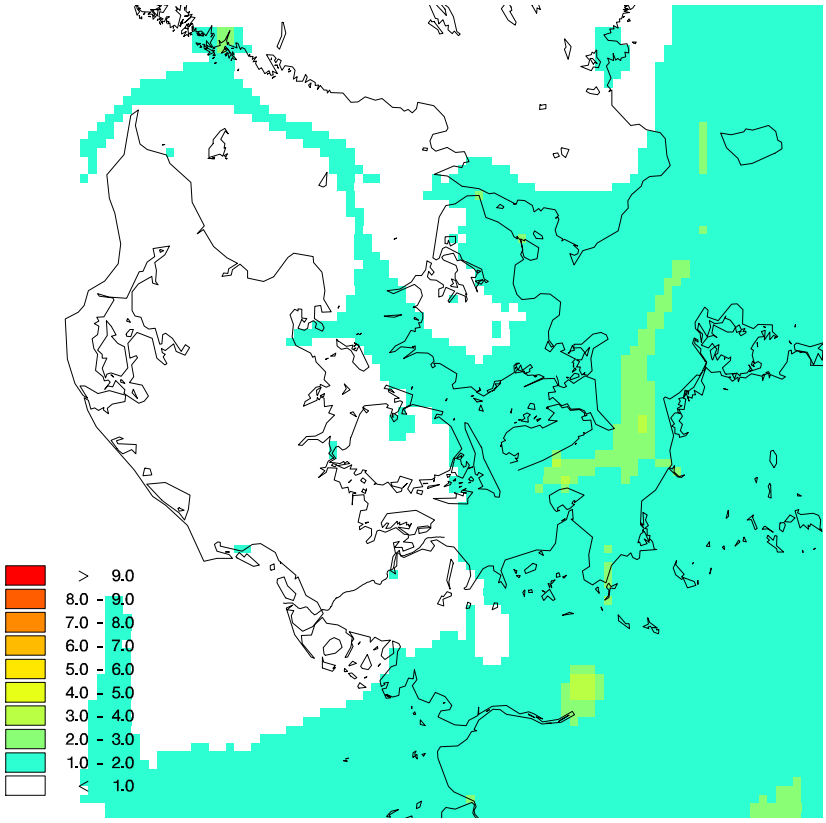

Figure 9.5. Winter mean concentrations of SO_2 (µg/m^3) for 2008 calculated with DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model. The high concentrations calculated for the inner Danish waters are due to emissions from ships.

10 Polyaromatic Hydrocarbons (PAHs)

Following the Directive 2004/107/EC of the European Parliament (EC, 2005), measurement of atmospheric concentrations of benzo[a]pyrene and other particle bound PAHs have been introduced in the Danish Air Quality Monitoring Programme (LMP) starting from June 2007. The target value for benzo[a]pyrene in ambient air is set to 1 ng/m^3 averaged over a calendar year. Benzo[a]pyrene is used as a marker for the carcinogenicity of PAHs.

10.1 Sampling and analysis

Particulate matter (PM10 fraction) is collected at the urban station of H.C. Andersen Boulevard (1103) in Copenhagen by high volume sampling (HVS) at a flow rate of 0.5 m^3 min^{-1} over a period of 24 hours, for an average total volume of 700 m^3.

The filters are kept frozen until analysis. A quarter of a filter is extracted by Accelerated Solvent Extraction (ASE) with a mixture of dichloromethane/hexane (50:50, v/v). Before extraction, the filters are spiked with deuterium-labelled PAH. Clean up of the extracts is performed on line in the extraction cell by adding activated silica.

Analysis of the extracts is carried out by gas chromatography-mass spectrometry (GC-MS). Concentrations of individual PAH in samples are corrected for recovery of a deuterium-labelled PAH standard with the closest molecular weight. A total of 18 PAHs are analyzed in the method.

10.2 Results

The average concentration of benzo[a]pyrene measured in Copenhagen was 0.40 ng/m^3 in 2008. The minimum, maximum and average monthly concentrations of benzo[a]pyrene are summarized in Table 10.1.

The average concentrations of the other five PAH listed as relevant in the EU Directive were the following: benzo[a]anthracene, 0.34 ng/m^3; benzo[b]fluoranthene, 0.81 ng/m^3; benzo[j+k]fluoranthenes, 0.29 ng/m^3; indeno[1,2,3-cd]pyrene, 0.35 ng/m^3; dibenzo[a,h]anthracene 0.10 ng/m^3.

The seasonal trends in PAH concentrations are summarized in Figure 10.1. As expected, the atmospheric concentrations are low during summer months, while concentrations increase in winter months due to higher emissions and less photochemical degradation of the compounds. It can be conclude that the target value for benzo[a]pyrene on 1 ng/m^3 was not exceeded in 2008.

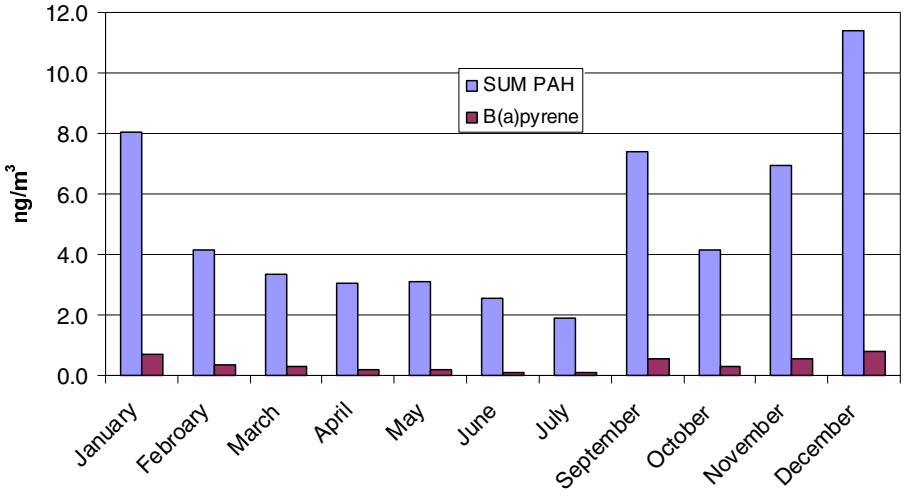

Figure 10.1 Monthly average concentrations in 2008 of benzo[a]pyrene (B(a)P) and the sum of the analysed PAH.

Table 10.1 Daily minimum, maximum and average monthly concentrations (ng/m3) of benzo[a]pyrene during 2008.

Month	Minimum conc.	Maximum conc.	Average conc.
January	0.13	5.28	0.70
February	0.10	1.00	0.34
March	0.11	0.66	0.28
April	0.09	0.55	0.20
May	0.01	0.44	0.18
June	0.01	0.33	0.12
July	0.05	0.19	0.11
September	0.11	1.43	0.55
October	0.15	0.83	0.30
November	0.15	1.72	0.56
December	0.18	2.06	0.82

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Appendix 1

Pollutants measured in the LMP Network

NO and partly NO_2 are formed by combustion at high temperatures. The main sources are power plants and traffic. At the street stations the traffic is the main source. The application of catalytic converter in the exhaust reduces the emission considerably. NO is relatively harmless, but NO_2 can cause respiratory problems.

Most of the NO_2 in the urban atmosphere is produced by oxidation of nitrogen monoxide (NO) by ozone (O_3). The reaction will take place immediately, if sufficient O_3 is present. O_3 is often the limiting component for a complete oxidation in the street canyons, but practically all NO is oxidised at the urban background and rural stations. Within a few hours the NO_2 is further oxidised to nitrate and/or nitric acid, which may cause acid precipitation and eutrofication. NO_2 is a toxic gas, which may cause respiratory problems. There are limit values for the allowed concentration of NO_2 in the atmosphere.

O_3 is formed by photochemical reactions (i.e. by the influence of sunlight) between nitrogen oxides and volatile organic compounds (VOC's). The VOC's can be of natural and anthropogenic origin. The major part of the O_3 measured in Denmark originates from sources outside the country. Usually the highest concentrations are found at rural and urban background sites. O_3 is removed by NO at street level. O_3 is a toxic gas, which may cause respiratory problems and damage on crops and forests. There are so-called target values for the concentration of O_3 in the atmosphere.

The main source of CO in urban air is petrol-fuelled cars. The CO is formed due to incomplete combustion. The application of catalytic converter in the exhaust reduces the emission considerably. CO is only slowly removed from the atmosphere. CO is a toxic gas that may prevent the uptake of oxygen in the blood. There are limit values for the allowed concentration of CO in the atmosphere.

Benzene is present in petrol. It may also be formed in engines due to incomplete combustion. Since 1994 the benzene content in petrol has been reduced by up to a factor of 5. The concentration in the atmosphere has been reduced correspondingly. Benzene is a carcinogenic gas. There is a limit value for the average content in the atmosphere.

Many different VOC's are present in the air. Several of these are emitted by incomplete combustion in e.g. engines and wood burning stoves. Several of the VOC's are carcinogenic. A "target value" is implemented through an EU Council Directive in 2004 for Benzo(a)-pyrene as indicator for PAH (Polycyclic Aromatic Hydrocarbones). Of the VOC's only benzene, toluene and xylenes are measured routinely in LMP IV at present.

The main sources for PM_{10} and $PM_{2.5}$ are combustion and resuspended dust. PM are also produced by chemical reactions in the atmosphere e.g. oxidation of nitrogen dioxide, sulphur dioxide and VOC. The submicron particles, which are formed by combustion and chemical reactions in the atmosphere, are suspected to be the most harmful for the health. There are still a lack of knowledge about the connection between health effects and particle size. Limit values for the PM_{10} concentration in the atmosphere are implemented at present. The limit values are under revision and will include $PM_{2.5}$. The limit values will be currently reviewed when better knowledge about the adverse health effects of fine particles influence on health is obtained.

PM_{10} and $PM_{2.5}$ is measured using two different methods in the LMP program:

- The particles are collected on filters in 24^{h} intervals. The mass on the filters is determined by measurements of β-absorption in the dust. This method is considered to be equivalent to the reference method (EN 12341:1999 and EN14907:2005).
- The particles are collected on a "tapered oscillating microbalance" (TEOM) and heated to 50°C. During heating volatile compounds may evaporate. The loss will be most pronounced for "secondary aerosols" containing ammoniumnitrate.

There are a number of different HM's in the atmosphere. They are emitted from e.g. coal and oil fired power plants, waste incinerators and industries. HM's may also be emitted from traffic due to wear on engines, tires and brake pads. Several HM's are toxic even in low concentrations and a few also carcinogenic. A limit value is implemented for lead. Target values are values are implemented for arsenic, cadmium, nickel and mercury. WHO has proposed guideline values for the toxic non-carcinogenic and estimated life time risks for the carcinogenic HM's.

Sulphur dioxide (SO_2) is formed by burning of fossil fuel and biomass. The SO_2 is oxidised in the atmosphere to particulate sulphuric acid and sulphate. The conversion time depends strongly on the temperature and humidity in the air. It is typically of the order of one day. Sulphuric acid contributes to "acid rain" and the deposition of sulphate causes damage to sensitive ecosystems. During the last 20 years the reduction of sulphur in fossil fuel and improved flue gas cleaning has reduced the concentration of SO_2 with one order of magnitude. SO_2 may cause respiratory problems. There are limit values for the allowed concentration of SO_2 in the atmosphere.

Appendix 2 Estimate of PM_{10} at H.C. Andersens Boulevard

Measurements of PM_{10} is carried out by NERI using two different methods at the street station at H.C. Andersens Boulevard (HCAB, Copenhagen/1103) and at the urban background station at H.C. Ørsteds Institute (HCØ, Copenhagen/1259):

- SM200: The primary measurements on diurnal basis. These measurements are in agreement with EU's reference method.
- TEOM: Research oriented measurements with averaging time of half an hour. TEOM has a known bias that results in too low values for PM_{10} compared to SM200. The bias is due to evaporation of a minor part of the particle mass prior to determination of PM_{10}. Diurnal averages of TEOM-PM_{10} is used in this context.

PM_{10} on a street can be divided in 1) a local contribution from the traffic (exhaust, dust from road and brakes etc.), 2) an urban background from the surrounding city area, and 3) a regional contribution due to wind blown transport of particles from outside the city area.

Based on results from NERI's research projects on particles (P. Wåhlin, Technical report from NERI no. 688, 2008) it is documented that the bias of TEOM has no effect on the measurements of the part of PM_{10} that originate from the local traffic. The difference between PM_{10} measured on a street station and in urban background do not depend on whether it is measured using SM200 or TEOM i.e. ($TEOM_{street} - TEOM_{urban\ background}$) equals ($SM200_{street} - SM200_{urban\ background}$).

The local contribution from traffic at HCAB can therefore be estimated from the difference between TEOM measurements of PM_{10} at HCAB and HCØ. Measurements of PM10 using SM200 at HCØ correspond to the sum of PM_{10} for urban and regional background. An estimate of the total PM_{10} at HCAB can therefore be calculated directly from the measurements of PM_{10} using SM200 at HCØ and TEOM at HCAB and HCØ. Here called the NERI estimate.

The validity of this estimate is confirmed by comparing measurements of PM_{10} using SM200 and the NERI estimate (Figure 1). For all days in 2006-2008, where the necessary data sets are available (i.e. PM_{10} from SM200 and TEOM at both HCAB and HCØ). From Figure 1 it can be seen that the agreement is good between the SM200 measurements and the NERI estimate (slope = 1.00) and a good correlation ($R^2 = 0.90$).

In connection to EU it has been an accepted praxis to make a simple correction of TEOM measurements of PM_{10} in order to compensate for the evaporation of the semi volatile particles. This correction is simply to multiply the TEOM-PM_{10} by a factor of 1.3. Figure 2 shows a comparison from HCAB between measurements of PM_{10} using SM200 and an estimate of PM10 calculated by correction of TEOM-PM_{10} by multiplication with 1.3. Again agreement between PM_{10} measurements and estimate is

good (slope = 0.98). However, the correlation is not as good for the simple estimate (R^2 = 0.80) as for the NERI estimate (R^2 = 0.90).

It can be concluded that the NERI estimate gives results in good agreement with the direct measurements using SM200 and the estimate is therefore in agreement with the reference method. Moreover, the correlation between the direct measurements and the NERI estimate is better than the correlation between direct measurements and the simple estimate. It is therefore also concluded that the NERI estimate gives better results for PM_{10} at HCAB compared to the simple estimate using a factor of 1.3.

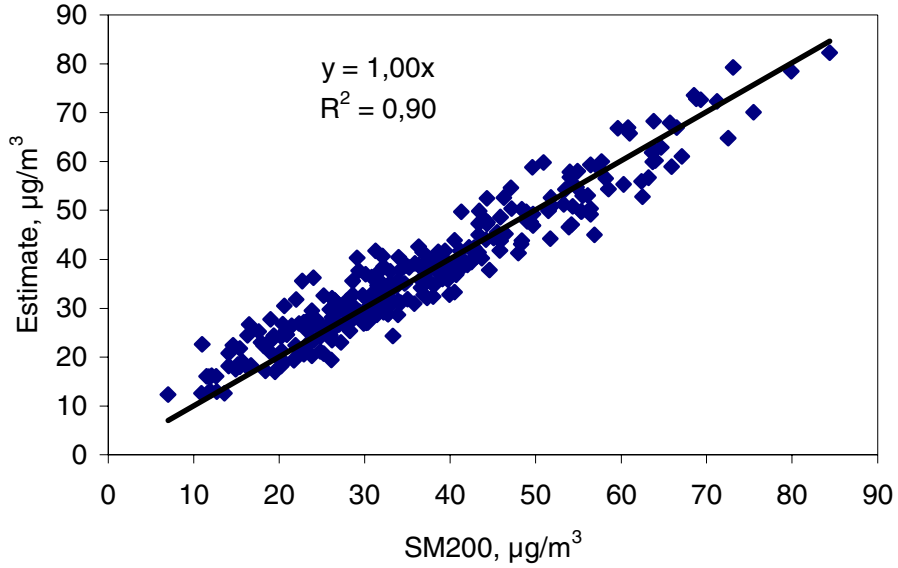

Figure 1. Comparison of the direct measurements of PM10 using SM200 and the NERI estimate of PM10 for the period 2006 to 2008 at HCAB. The NERI estimate is determined on basis of measurements of PM10 using TEOM at HCAB and HCØ in addition to measurements of PM10 using SM200 at HCØ. Data from 278 days. The regression line is a simple linear regression forced through (0,0). All values are given at 0 ºC and 1 atm.

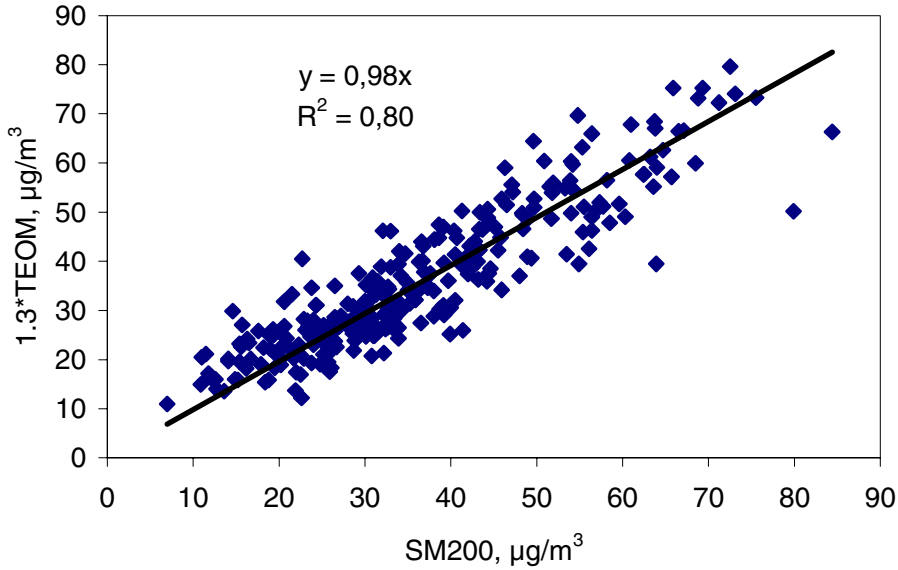

Figure 2. Comparison of the direct measurements of PM_{10} using SM200 and the simple estimate of PM_{10} for the period 2006 to 2008 at HCAB. The simple estimate is calculated by multiplication of TEOM-PM_{10} with a factor of 1.3. Data from 278 days. The regression line is a simple linear regression forced through (0,0). All values are given at 0 ºC and 1 atm.

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THE DANISH AIR QUALITY MONITORING PROGRAMME

Annual Summary for 2008

The air quality in Danish cities has been monitored continuously since 1982 within the Danish Air Quality Monitoring (LMP) network. The aim is to follow the concentration levels of toxic pol-lutants in the urban atmosphere and to provide the necessary knowledge to assess the trends, to perform source apportionment, and to evaluate the chemical reactions and the dispersion of the pollutants in the atmosphere. In 2007 the air quality was measured in four Danish cities and at two background sites. Model calculations were also carried out to supplement the measure-ments. At several stations NO2 and PM10 were found in concentrations above EU limit values, which the Member States have to comply with in 2005 and 2010. The concentrations for most pollutants have been strongly decreasing since 1982, however, only a slight decrease has been observed for NO2 and O3.

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