
# THE DANISH AIR QUALITY MONITORING PROGRAMME

## Annual Summary for 2009

NERI Technical Report no. 799 2010

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

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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 understand the governing processes that determine the level of air pollution in Denmark. In 2009 the air quality was measured in four Danish cities and at two background sites. In addition model calculations were carried out to supplement the measurements. At the two street stations in Copenhagen $NO_2$ was found in concentrations above EU limit values plus margin of tolerance. In the previous years $PM_{10}$ was above the limit value. However, in 2009 $PM_{10}$ has decreased at H.C.Andersens Boulevard and no exceedance of the limit value was observed. The concentrations for most pollutants have been strongly decreasing during the last decades, however, only a slight decrease has been observed for $NO_2$ and $O_3$.



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# Summary and Conclusion

This report presents the result of the Danish Air Quality Monitoring Programme (LMP) in 2009. The monitoring programme is carried out by the National Environmental Research Institute (NERI) at University of Aarhus. The programme is based on continuous measurements at nine monitoring stations situated in the four largest cities and two stations in background areas. These measurements are supplemented with model calculations using NERI's air quality models.

The aim of the program is to monitor air pollutants relevant to human health in accordance with the EU air quality directives. The programme includes measurements of sulphur dioxide ($SO_2$) and particulate sulphur (S), nitrogen oxides ($NO_x/NO_2$), particulate mass ($PM_{10}$ and $PM_{2.5}$), benzene ($C_6H_6$) and toluene ($C_7H_8$) carbon monoxide (CO), ozone ($O_3$), lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg), nickel (Ni) and polycyclic aromatic hydrocarbons (PAH). In 2009 the programme was expanded with measurements of a number of volatile organic compounds (VOC's) that are precursors for formation of ozone. 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 pollutants. Further, the program serves as basis for evaluation of the impact of regulations of emissions and as basis for various research projects related to air quality.

In 2009 $PM_{10}$ at all the stations were below both the annual limit value (40 µg/m$^3$) and the limit value for the 35$^{th}$ highest daily average value for $PM_{10}$ (50 µg/m$^3$). At H.C. Andersens Boulevard, Copenhagen a significant decrease (about 7 µg/m$^3$) in the $PM_{10}$ annual mean concentration was observed between 2008 and 2009; a decrease that mainly was due to new road astfalt. $PM_{2.5}$ was lower than the annual limit value (25 µg/m$^3$) valid from 2015.

The annual limit value including the margin of tolerance for $NO_2$ (42 µg/m$^3$ in 2009) was exceeded at both the street stations in Copenhagen, whereas no exceedance was observed in Odense, Aalborg and Aarhus. The annual limit value (to be complied with in 2010) was exceeded at four out of five street stations in 2009. The $NO_2$ concentrations have shown a slight decrease during the last twenty years. Model calculations at selected streets in Copenhagen and Aalborg indicate that the limit value including margin of tolerance were exceeded at several streets in central Copenhagen and Aalborg.

The ozone level was in 2009 almost the same as in 2008 at all rural and urban background stations and no clear trend was thus observed. The information threshold at 180 µg/m$^3$ was not exceeded. The target value for the max 8 hours ozone concentration on 120 µg/m$^3$ was also not exceeded, but the long-term objective for this target was exceeded at almost all non-traffic stations. The target value for AOT40 (18000 (µg/m$^3$)·h) was not exceeded and the long term target for AOT40 (6000 (µg/m$^3$)·h) was only exceeded in Ulborg and at Lille Valby, Roskilde.

The report presents results for volatile organic compounds (VOC) measured at the urban background in Copenhagen. VOC's can act as ozone precursors, although the formation of ozone in Denmark is in general small due to moderate solar radiation. The ozone pollution in Denmark is to a large extent caused by long distance transport of pollutants from other European countries.

The levels of $SO_2$ and heavy metals have decreased for more than two decades and are now far below the limit values. The limit values for benzene and CO are not exceeded and the levels have decreased for the last decade.

Measurements of particle bound PAH concentrations were performed at H.C. Andersens Boulevard, Copenhagen. The average concentration of benzo[a]pyrene was 0.25 ng/m$^3$. The target value for benzo[a] pyrene (1 ng/m$^3$) was not exceeded in 2009.

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 resultater for 2009 fra Overvågningsprogrammet for luftkvalitet i danske byer (LMP). Programmet, som udføres af Danmarks Miljøundersøgelser (DMU) ved Aarhus Universitet, er baseret på målinger ved 9 målestationer placeret i de fire største danske byer og ved to baggrundsmålestationer udenfor byerne. Disse målinger kombineres med anvendelse af modelberegninger med DMU's luftkvalitetsmodeller.

Formålet med programmet er at overvåge luftforurening af betydning for sundhed i overensstemmelse med EU's luftkvalitetsdirektiver. I henhold til disse måles koncentrationer af svovldioxid ($SO_2$) og partikulært sulfat (S), nitrogenoxider ($NO_x/NO_2$), partikelmasse ($PM_{10}$ og $PM_{2.5}$), benzen ($C_6H_6$) og toluen ($C_7H_8$), carbonmonooxid (CO), ozon ($O_3$), bly (Pb), arsen (As), cadmium (Cd), kviksølv (Hg), nikkel (Ni) og polyaromatiske kulbrinter (PAH) i luften i danske byer samt udvalgte flygtige kulbrinter (VOC), der kan føre til dannelse af ozon. Rapporten beskriver udviklingen i koncentrationerne og vurderer kilderne til de enkelte stoffer. 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 ikrafttrædelsestidspunktet er det 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 2010). Bekendtgørelsen er baseret på det 4. datterdirektiv om tungmetaller og PAH (EC 2005) samt det nye luftkvalitetsdirektiv vedtaget i 2008 (EC 2008). En af de væsentligste ændringer i det nye direktiv i forhold til det tidligere luftrammedirektiv og de tre første datterdirektiver (EC 1996, 1999, 2000 og 2002) 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 2009 er følgende:

- Generelt var niveauerne i 2009 på samme niveau som i 2008. Ændringerne vurderes hovedsageligt at skyldes meteorologiske forhold.
- I 2009 var koncentrationerne af kvælstofdioxid ($NO_2$) på fire målestationer (gadestationerne i København, Aarhus og Aalborg) over grænseværdierne, som skal overholdes fra 2010. Grænseværdien + tilladte margin i 2009 (42 $\mu g/m^3$) blev kun overskredet på de to gadestationer i København. Hertil kommer, at modelberegninger indikerer, at grænseværdi inklusiv den tilladte margin var overskredet på et stort antal gadestrækninger i centrum af København og på gadestrækninger i Aalborg.

- I 2009 var der ingen målestationer, hvor grænseværdierne for luftens indhold af partikler mindre end 10 µm ($PM_{10}$) blev overskredet. I 2008 var der kun overskridelse på én målestation i København (H.C. Andersens Boulevard, HCAB), men $PM_{10}$ på HCAB faldt med ca. 7 µg/m$^3$ fra 2008 til 2009, således at der ikke længere er overskridelse af grænseværdien. Årsagen til det betydelige fald er hovedsageligt ny asfalt på HCAB.
- Indholdet af partikler mindre end 2.5 µm ($PM_{2.5}$) overskred ikke de kommende grænseværdier, som skal overholdes fra 2015.
- Der er ikke fastsat egentlige grænseværdier for ozon ($O_3$), men kun "målværdier" og "langsigtede mål" (hensigtsværdier). Der var i 2009 ingen overskridelser af målværdierne for beskyttelse af sundhed og vegetation, mens de langsigtede mål blev overskredet på en stor del af bybaggrunds- og landstationerne.
- De øvrige målte stoffer findes i koncentrationer under grænseværdierne, og for flere stoffer (fx svovldioxid og bly) er koncentrationerne faldet betydeligt siden målingernes start.
- Målinger af partikelbundet PAH blev fortaget på H.C. Andersens Boulevard i København. Middelværdien for benz[a]pyren var 0,25 ng/m$^3$. Målværdien på 1 ng/m$^3$ var således ikke overskredet i 2009.
- For første gang præsenterer rapporten resultater for måling af udvalgte flygtige organiske kulbrinter (VOC) i bybaggrund i København. Disse VOC bidrager til den kemiske dannelse af ozon i Europa. I Danmark skyldes størstedelen af ozon langtransport af luftforurening fra den sydlige del af Europa.

# 1 Introduction

The Danish Air Quality Monitoring Programme (LMP) originates back to 1981. Today the programme is part of the National Monitoring Programme for the aquatic and terrestrial environment (NOVANA). The program consists of an urban monitoring network with stations in the four largest Danish cities and two back ground stations in rural areas (figure 2.1) which is supplemented by model calculations. The results are used for assessment of the air pollution in Denmark with special focus on air quality in Danish urban areas. The programme is carried out in co-operation between the National Environmental Research Institute at Aarhus University (NERI), the Danish Environmental Protection Agency, the Municipalities of Copenhagen, Aarhus, Aalborg and Odense. NERI is responsible for the practical programme. 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. This report also presents results from model calculations of air quality in Denmark carried out as supplement to the measurements in LMP.

The programme is carried out in accordance with the Danish Statutory Order No. 851 of 30 June 2010 from the Ministry of Environment (Miljøministeriet 2010) that implements the EU directives on air quality in Denmark. The EU legislation consisted previously 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. Four 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) had been adopted. In 2008 a new directive (EC, 2008) was adopted that replaced the framework directive and the three first daughter directives. This new directive is now implemented through the Danish statutory order (Miljøministeriet 2010). One of the major changes in the new directive is that monitoring of $PM_{2.5}$ is now part of the measurement programme.

One of the main objectives for the monitoring programme is to assess the air quality in relation to various air quality criteria (i.e. limit values, margin of tolerance, target values, long term objectives and alert thresholds) of which the limit values are the legally most important. The Danish quality criteria's are identical with those laid down in the EU directives described above. The limit values must in most cases be attained in 2005 or 2010. Until then a so-called margin of tolerance is added to the limit values. The margin of tolerance is reduced annually in equal sized steps and attend zero in the year when the limit value enter into force.

In the following chapters the results from measurements and model calculations for 2009 are presented and compared to limit and threshold values. Please refer to the EU Directives for a detailed description of the exact definitions of the limit values, margin of tolerance, target values and alert thresholds.

# 2 Measurements and model calculations

The measuring strategy is in short to place one or more pairs of stations in each of the four largest Danish cities. 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.

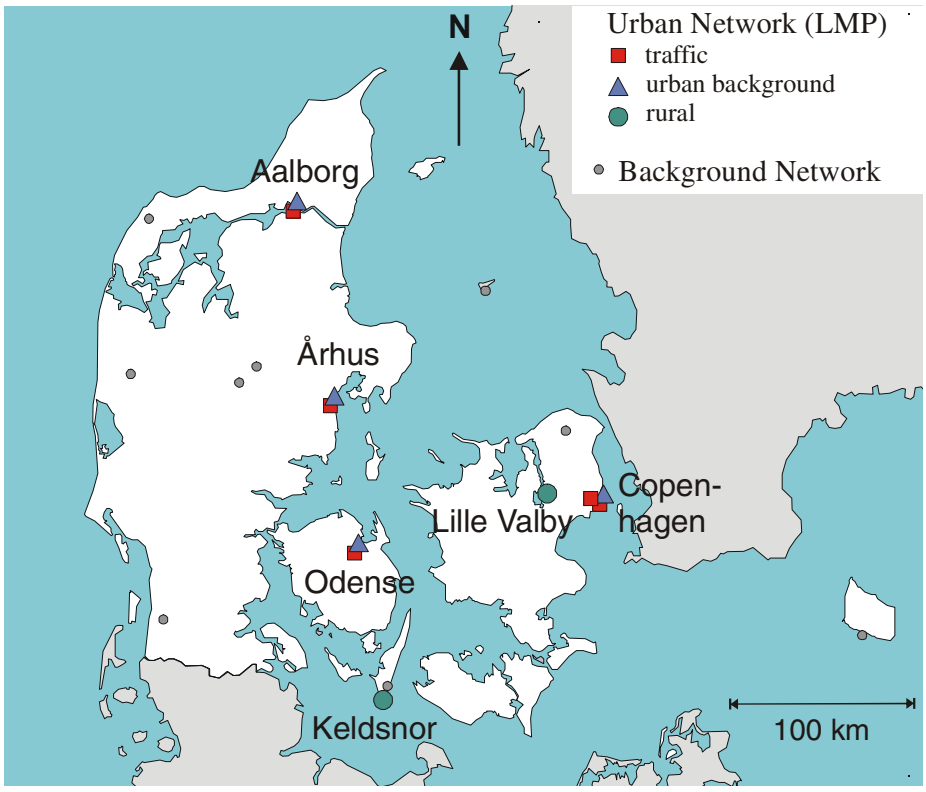



**Figure 2.1** Monitoring stations in the two nation-wide air quality networks.

**Table 2.1.** Stations in the LMP network included in this report for 2009

| Name | Street/location | Type |
|---|---|---|
| Copenhagen/1257 | Jagtvej | Street |
| Copenhagen/1259 | H.C. Ørsted Institute (HCØ) | Urban background |
| Copenhagen/1103 | H.C. Andersens Boulevard (HCAB) | 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 2009:

- Nitrogenoxides (nitrogenmonoxid (NO), $NO_2$ and $NO_x$ (= NO + $NO_2$) and particle mass ($PM_{10}$ and $PM_{2.5}$) were measured at all stations. PM was measured by means of β-absorption as 24 h averages.
- 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 and Copenhagen/1259 by means of TEOM that measures with high time resolution. $PM_{2.5}$ was also measured at Copenhagen/1103, Copenhagen/1259 and Lille Valby/2090 by means of TEOM. Part of these measurements was carried out in a research project funded separately 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 as well as at 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.
- 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, $NO_2$, $O_3$, CO, $SO_2$) were recorded as ½-hour averages. Particle mass ($PM_{10}$ and $PM_{2.5}$) 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 as well as 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.

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/En/Air.

In LMP the measurements at the permanent measurement stations are supplemented with model calculations using the Thor modelling system (Brandt et al., 2000). 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 as-

similation (FDDA) in the meteorological model MM5v3 (Grell et al., 1995). The meteorological data from MM5v3 is subsequently 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 3D 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 2009 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 2008 made by NERI (www.dmu.dk) and international emission inventories for the year 2007 collected and distributed by EMEP (www.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 as input 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 2009 conditions. The emission factors and the composition of the vehicle fleet have been updated with recent data used in the national emission reporting. The input data for the OSPM model on traffic volume and street configurations for the selected urban streets are generated using the AirGIS system (Jensen et al., 2001; http://airgis.dmu.dk).

The model calculations for 2009 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 Yearly statistics

**Table 3.1.** Nitrogen dioxide ($NO_2$) in 2009. All parameters are calculated with hourly averages.

| Unit: µg/m$^3$ | Number | Average | Median | 98. percentile | 19. highest |
|---|---|---|---|---|---|
| *Traffic:* | | | | | |
| Copenhagen/1257 | 8177 | 43*) | 38 | 110 | 160 |
| Copenhagen/1103 | 7704 | 50*) | 46 | 108 | 143 |
| Århus/6153 | 8118 | 41 | 38 | 95 | 121 |
| Odense/9155 | 8085 | 31 | 25 | 88 | 119 |
| Aalborg/8151 | 8286 | 41 | 34 | 114 | 141 |
| *Urban Background:* | | | | | |
| Copenhagen/1259 | 7003 | 18 | 15 | 53 | 68 |
| Århus/6159 | 7705 | 18 | 15 | 55 | 71 |
| Odense/9159 | 8307 | 16 | 14 | 46 | 68 |
| Aalborg/8158 | 8300 | 17 | 12 | 62 | 98 |
| *Rural:* | | | | | |
| Lille Valby/2090 | 8255 | 10 | 7 | 36 | 53 |
| Keldsnor/9055 | 7833 | 9 | 7 | 34 | 56 |
| Limit values/limit value + margin of tolerance for 2009 | >7455 | 40/42 | | | 200/210 |

*) Limit value + margin of tolerance exceeded.

**Table 3.2.** Nitrogen oxides ($NO_x$=NO+$NO_2$) 2009. All parameters are calculated with hourly averages.

| Unit: µg/m$^3$ (as $NO_2$) | Number | Average | Median | 98. percentile | 19. highest |
|---|---|---|---|---|---|
| *Traffic:* | | | | | |
| Copenhagen/1257 | 8177 | 90 | 72 | 297 | 493 |
| Copenhagen/1103 | 7704 | 107 | 87 | 315 | 467 |
| Århus/6153 | 8118 | 90 | 71 | 300 | 448 |
| Odense/9155 | 8085 | 68 | 41 | 295 | 488 |
| Aalborg/8151 | 8286 | 112 | 78 | 413 | 601 |
| *Urban Background:* | | | | | |
| Copenhagen/1259 | 7003 | 22 | 17 | 74 | 131 |
| Århus/6159 | 7705 | 25 | 18 | 101 | 207 |
| Odense/9159 | 8307 | 21 | 16 | 73 | 146 |
| Aalborg/8158 | 8300 | 24 | 14 | 124 | 312 |
| *Rural:* | | | | | |
| Lille Valby/2090 | 8255 | 11 | 8 | 47 | 92 |
| Keldsnor/9055 | 8307 | 10 | 7 | 42 | 71 |

The limit values are from EU Directive 2008/50/EC (EC, 2008).

## 3.2 Episodes

**Table 3.3.** Episodic results for Nitrogen dioxide ($NO_2$) in 2009. All parameters are calculated with hourly averages.

| Unit: µg/m$^3$ | Max. 3 hours | Date | Hour | Max. hour | Date | Hour |
|---|---|---|---|---|---|---|
| *Traffic:* | | | | | | |
| Copenhagen/1257 | 185 | 090424 | 5 | 208 | 090216 | 8 |
| Copenhagen/1103 | 176 | 090403 | 23 | 226 | 090404 | 0 |
| Århus/6153 | 115 | 091214 | 17 | 162 | 091208 | 7 |
| Odense/9155 | 138 | 091202 | 8 | 179 | 091202 | 8 |
| Aalborg/8151 | 163 | 091221 | 8 | 181 | 091221 | 9 |
| *Urban Background:* | | | | | | |
| Copenhagen/1259 | 80 | 090404 | 0 | 100 | 090404 | 0 |
| Århus/6159 | 84 | 091214 | 17 | 93 | 090501 | 4 |
| Odense/9159 | 86 | 091202 | 8 | 122 | 091202 | 8 |
| Aalborg/8158 | 135 | 090105 | 8 | 162 | 090105 | 8 |
| *Rural:* | | | | | | |
| Lille Valby/2090 | 58 | 090404 | 4 | 74 | 090404 | 4 |
| Keldsnor/9055 | 59 | 090109 | 1 | 80 | 090714 | 23 |
| Alert threshold | 400 | - | | - | - | |

**Table 3.4.** Episodic results for Nitrogen oxides (NOx=NO+$NO_2$) in 2009. 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 | 258 | 090403 | 12 | 669 | 091105 | 11 |
| Copenhagen/1103 | 307 | 090918 | 8 | 879 | 090918 | 5 |
| Århus/6153 | 384 | 091202 | 13 | 812 | 091202 | 8 |
| Odense/9155 | 465 | 091202 | 15 | 1261 | 091202 | 8 |
| Aalborg/8151 | 417 | 091221 | 15 | 855 | 091221 | 9 |
| *Urban Background:* | | | | | | |
| Copenhagen/1259 | 80 | 091028 | 15 | 222 | 091028 | 9 |
| Århus/6159 | 165 | 091214 | 36 | 331 | 091214 | 20 |
| Odense/9159 | 216 | 091202 | 13 | 736 | 091202 | 8 |
| Aalborg/8158 | 285 | 090105 | 15 | 736 | 090105 | 8 |
| *Rural:* | | | | | | |
| Lille Valby/2090 | 52 | 090403 | 13 | 133 | 090403 | 7 |
| Keldsnor/9055 | 41 | 090109 | 6 | 94 | 090630 | 16 |

The Alert threshold for maximum 3 hours concentration of $NO_2$ is given in EU Directive 2008/50/EC (EC, 2008).

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

## 3.3 Trends

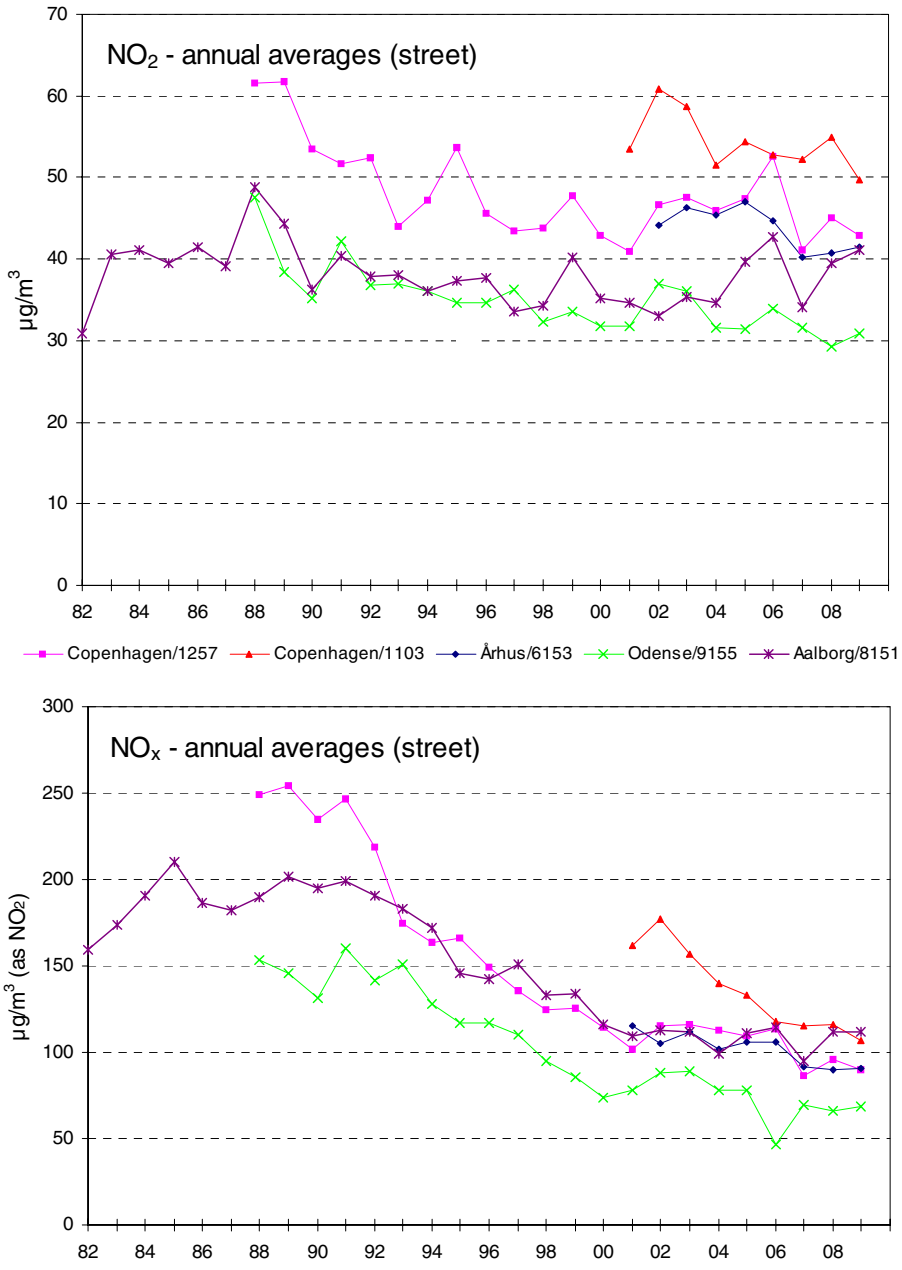



**Figure 3.1** The graphs show the time series for the annual average values measured at street stations. Previous results from Copenhagen/1103 can be found at the homepage of Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk)

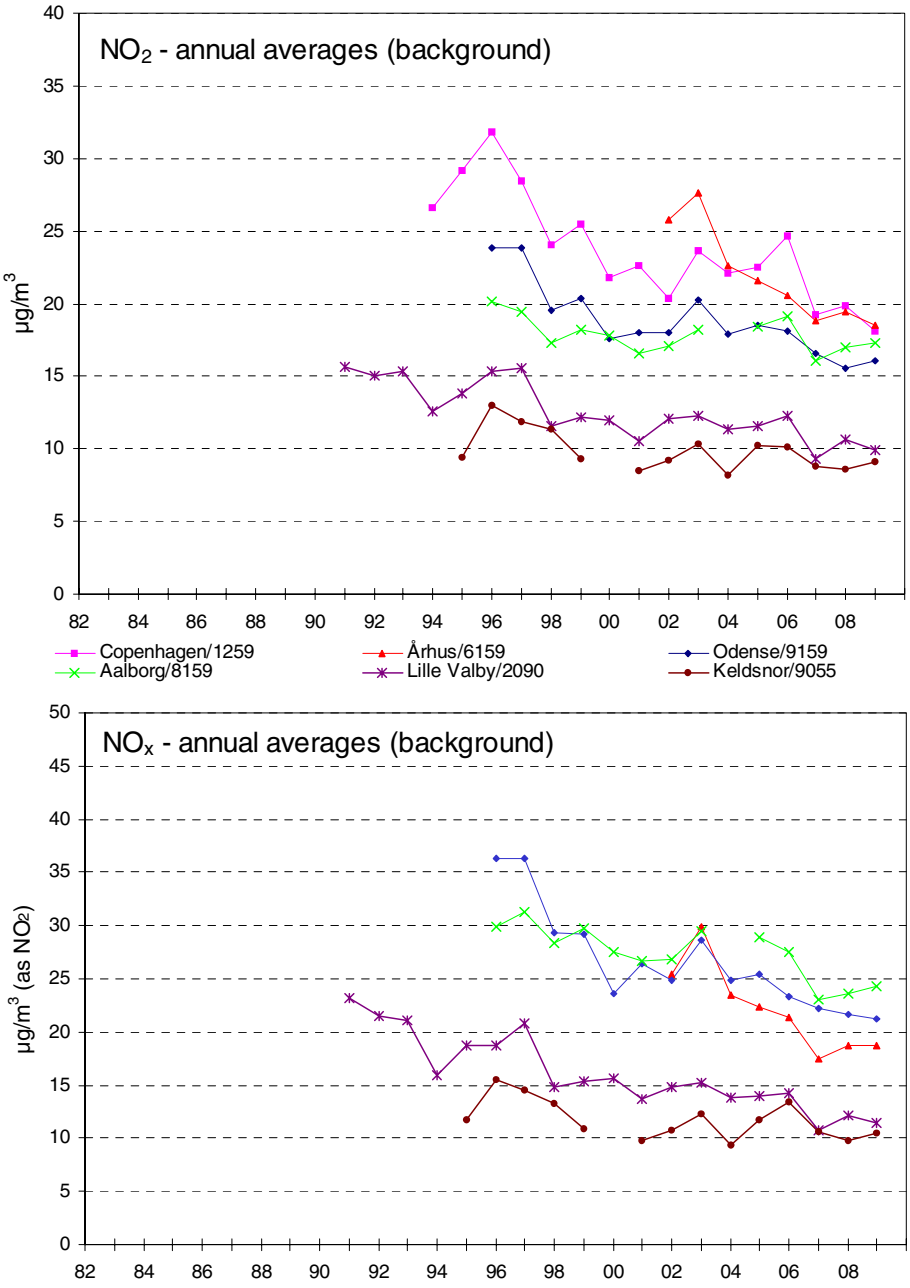



**Figure 3.2** The graphs show the time series for the annual average values measured at urban background and rural stations.

## 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 in a resolution of 5.6 km x 5.6 km for the entire country.

The selected streets represent busy streets and are mainly street canyons. Concentrations are elevated in this type of streets due to the high emissions and restricted dispersion conditions. 138 streets were selected in Copenhagen and 32 in Aalborg. Average Daily Traffic (ADT) was between 10,000 and 67,000 vehicles/day in Copenhagen and between 3,500 and 28,000 vehicles/day in Aalborg. Based on information from

Aalborg municipality the ADT at Vesterbro next to the monitoring station has been updated to be about 28,000 vehicles/day compared to about 20,000 vehicles/day that was assumed in previous years.

Model calculations have been carried out in order to determine the annual concentrations and the 19th highest concentrations of $NO_2$ to be able to compare with limit values. The air quality limit value including margin of tolerance for the annual mean is 42 µg/m$^3$ and 210 µg/m$^3$ for the 19th highest concentration in 2009. 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 recalculated for 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. This year the COPERT emission data used in OSPM has been updated with the latest emission factors and the composition of the vehicle fleet has been updated according to the latest database used in the national emission reporting.

In Aalborg this modelling approach underestimated measured urban background concentrations. Therefore, emissions applied in the UBM model were scaled up with a factor of 2.8 and in this way calibrated to the measured urban background level at the monitoring station in Aalborg. Work is in progress in order to understand the difference between measurements and model results from UBM 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). UBM calculations, using scaled emissions in Aalborg, have been compared to the $NO_2$ measurements at the urban background monitoring stations in Copenhagen and Aalborg. At all urban and street stations the model predict $NO_2$ concentrations within ±5%.

Low emission zones have been implemented in Denmark for five urban areas: the municipalities of Copenhagen, Frederiksberg, Århus, Odense and Aalborg. The low emission zones are implemented in two stages. Particle filters on diesel-powered heavy-duty vehicles > 3.5 tons are required for emission standard Euro II and older by September 1, 2008 (stage one) and for Euro III and older by July 1, 2010 (stage two). The low emission zones came into force in Copenhagen on September 1, 2008 and in Aalborg on February 1, 2009.

Although the low emission zone requirements are not designed to reduce $NO_x$ emissions they are expected to have an impact on $NO_x$ emissions since some older heavy-duty vehicles are to some extend replaced with newer vehicles that comply with the Euro IV and V emission standards.

A separate study has been carried out for Copenhagen analyzing the full effect of the low emission zone regulation including stage two in 2010 (Jensen et al. 2010). A reduction of 3.4 µg/m$^3$ is predicted for the average $NO_2$ concentration for the 138 streets due to the low emission zone in 2010. The number of exceedances of the air quality limit value for annual mean of $NO_2$ (40 µg/m$^3$) in 2010 is predicted to be 65 out of 138 streets without the low emission zone. This is reduced to 35 exceedances in 2010 as a result of to the low emission zone requirements.

As part of an ongoing project, that evaluates the effects of the low emission zones on air quality in Denmark, the full effect of the low emission zones (stage two) will also be evaluated for Aalborg for 2010.

The calculations presented below for Copenhagen and Aalborg for 2009 do not include the effect of stage one of the low emission zone regulation although there will be an effect. The full effect of the regulation (stage two) does not appear until 2010 and therefore we will post pone the inclusion of the full effect of the low emission zones until the model calculations for 2010.

### 3.4.1 Model calculations for Copenhagen

The annual mean concentrations and the 19th highest concentrations of $NO_2$ for Copenhagen in 2009 are shown in Figure 3.3 and 3.4, respectively.

In 2009 the limit value for the annual mean concentration plus margin of tolerance was exceeded in 48 out of the 138 selected streets in Copenhagen (Figure 3.3). In 2008 the number of streets exceeding the limit value plus margin of tolerance was 57. This number has been reduced from 58 to 57 since the reporting for 2008 due to rounding to integer values. The reasons for the reduction between 2008 and 2009 are:

1. $NO_x$ emissions have been reduced due to the renewal of the vehicle fleet with newer less polluting vehicles and the scrapping of older cars.
2. The reduction in the calculated $NO_2$ concentrations is partly compensated by the lowering of the limit value (plus margin of tolerance) from 44 µg/m$^3$ in 2008 to 42 µg/m$^3$ in 2009. In average for all 138 streets, the calculated concentrations are reduced by about 3 µg/m$^3$ from 2008 to 2009.

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.

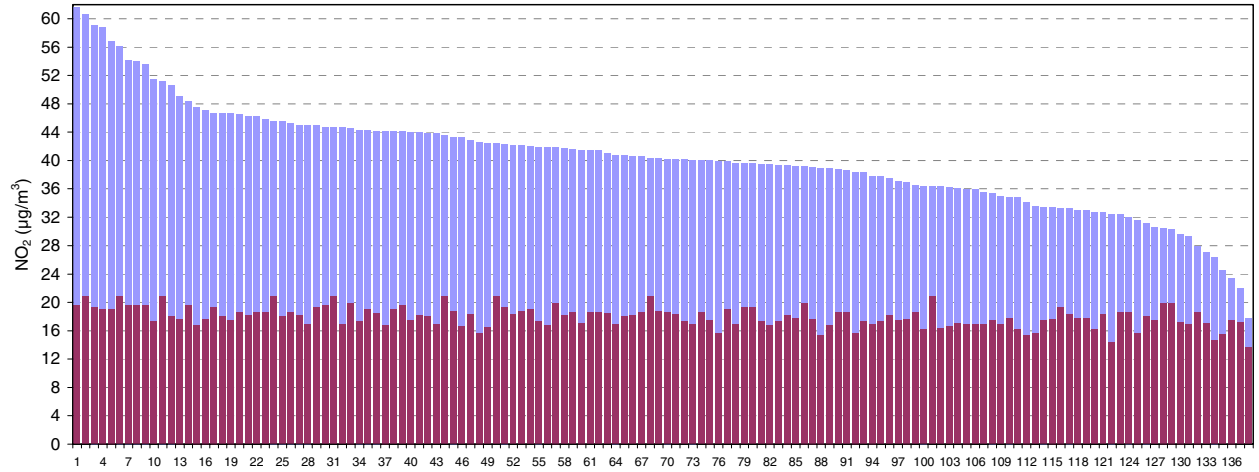



**Figure 3.3** Annual mean concentrations of $NO_2$ in 2009 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background (dark red colour) is obtained from calculations with the urban background model UBM with 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.

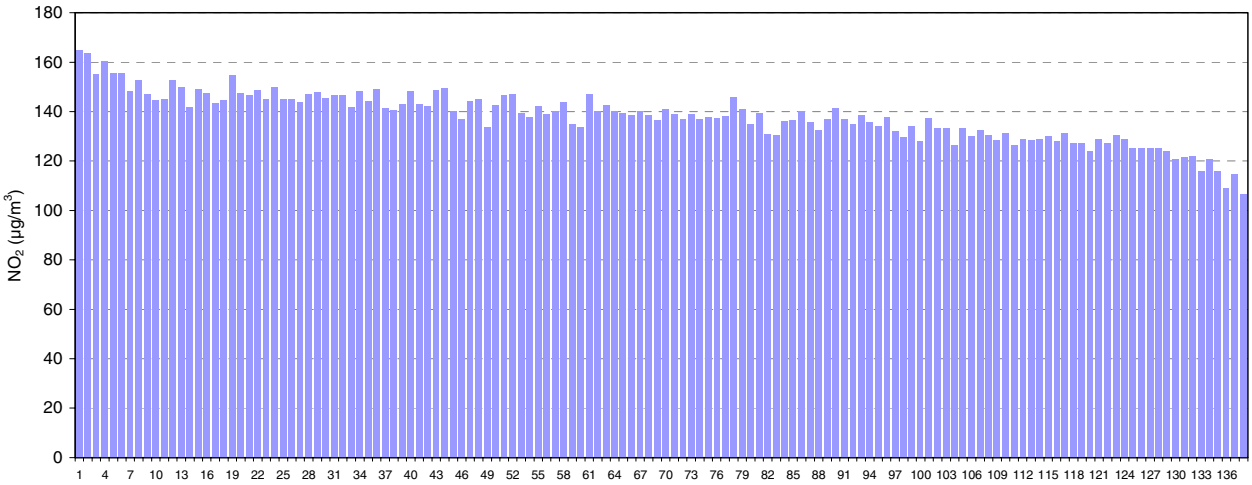



**Figure 3.4.** The 19th highest hourly mean concentration of $NO_2$ in 2009 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background model UBM with 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 12,000 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, openings in the building façade, the share of heavy-duty vehicles and orientation of the street have large impact on the concentration of $NO_2$ in a street.

The limit value plus margin of tolerance for the 19th highest concentration was 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 main roads but distributed 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 2009 (1 = highest, 138 = lowest). The numbers in parenthesis refer to different segments of the same street that has more than one model calculation.

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

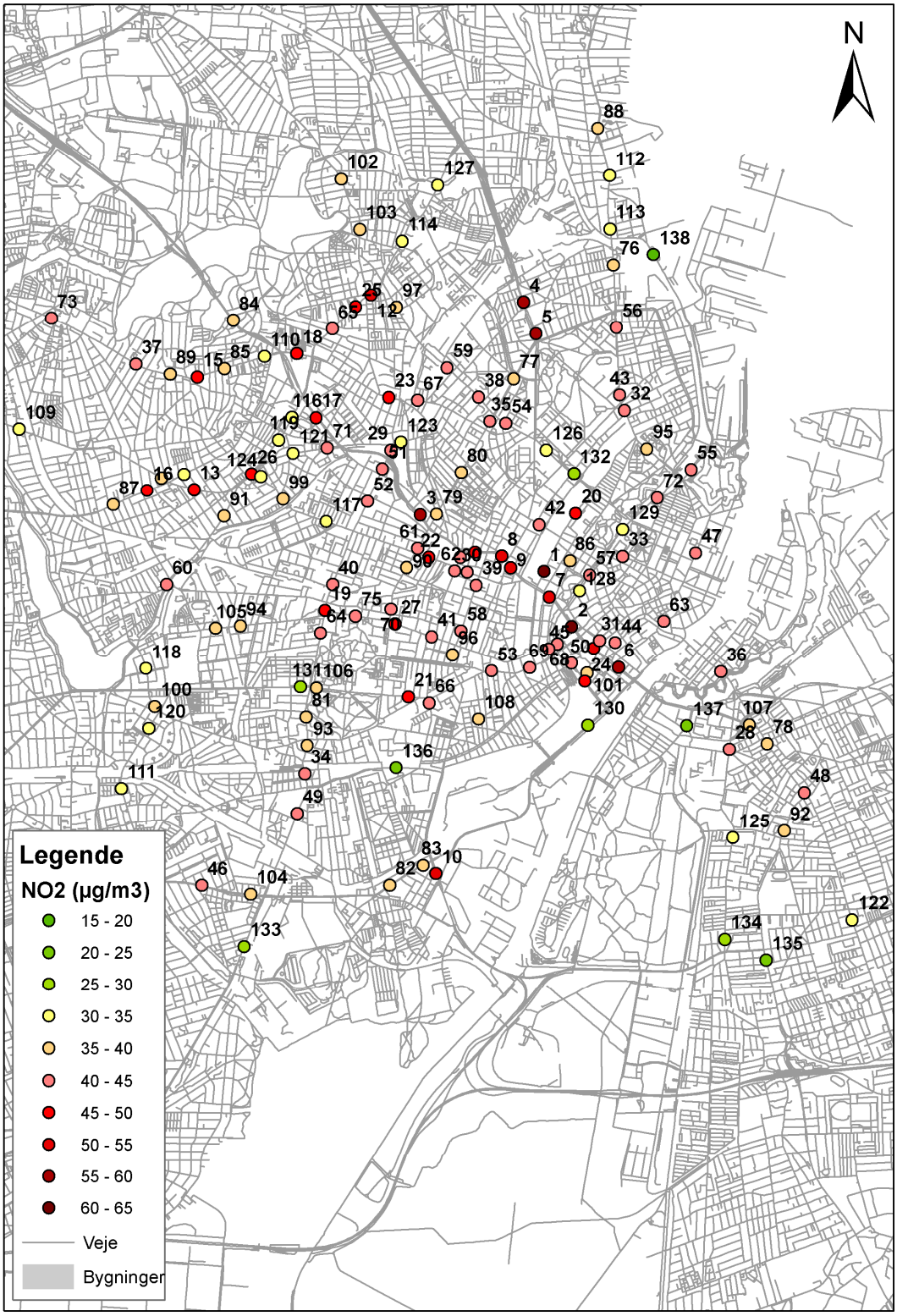



**Figure 3.5** Map showing the locations of the selected streets in Copenhagen and the annual mean concentrations of $NO_2$ for 2009. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban 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 in general a reduction in the $NO_2$ concentrations compared with 2008 for the same reasons given for Copenhagen in the previous section. The average $NO_2$ concentration was about 2 µg/m$^3$ lower in 2009 than in 2008.

According to the model calculations the limit value plus margin of tolerance for the annual mean concentration in 2009 was exceeded in 4 out of the 32 selected streets. This is the same number as in 2008 (Figure 3.6 and Figure 3.8).

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

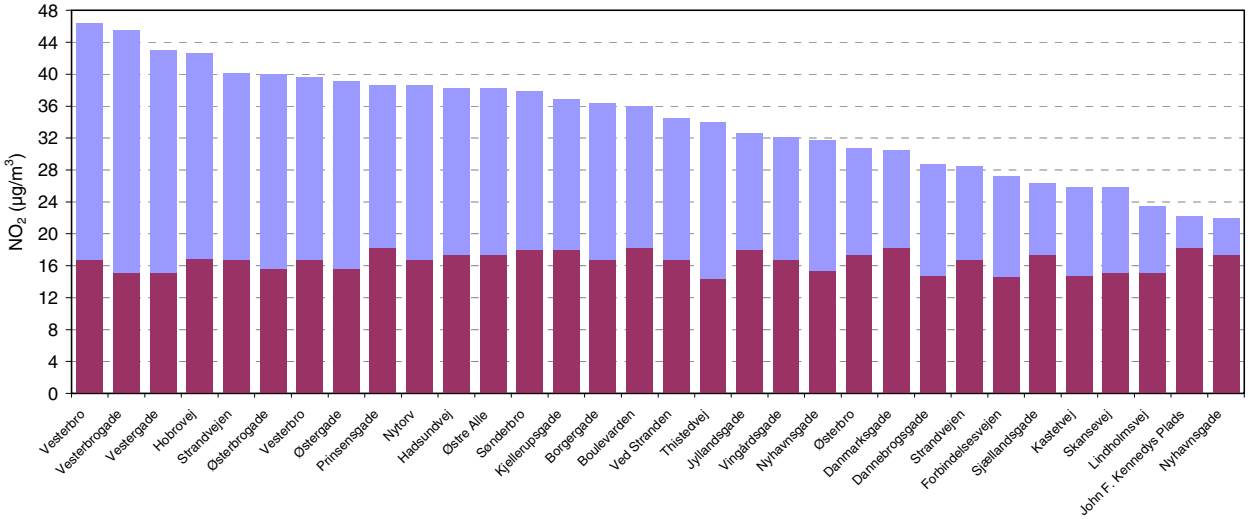



**Figure 3.6.** Annual mean concentrations of $NO_2$ in 2009 for 32 streets in Aalborg. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background (dark red colour) is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration.

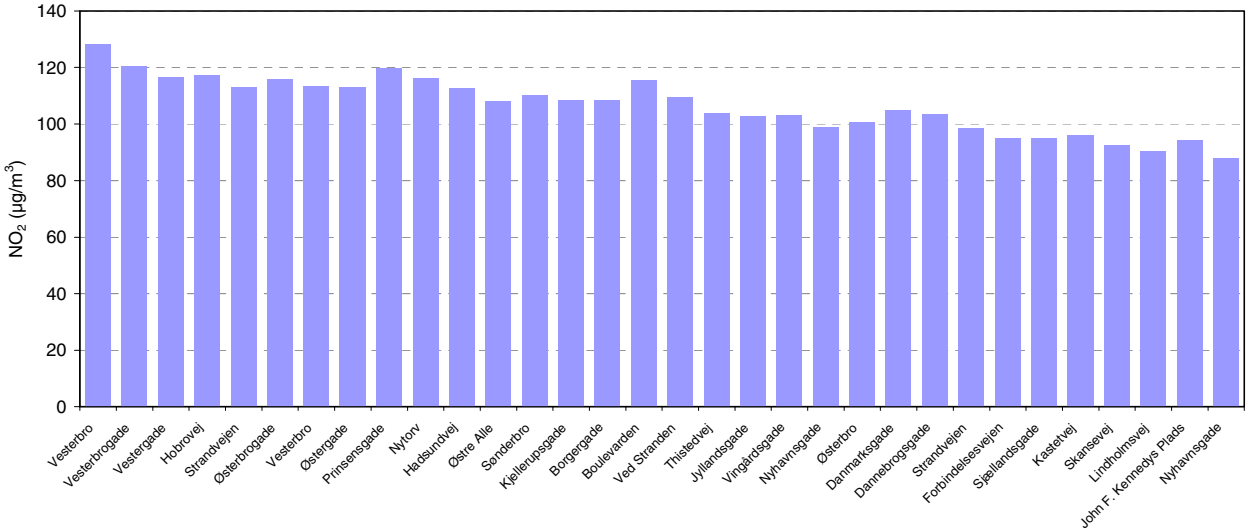



**Figure 3.7.** The 19$^{th}$ highest hourly mean concentration of $NO_2$ in 2009 for 32 streets in Aalborg. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background model UBM with 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.

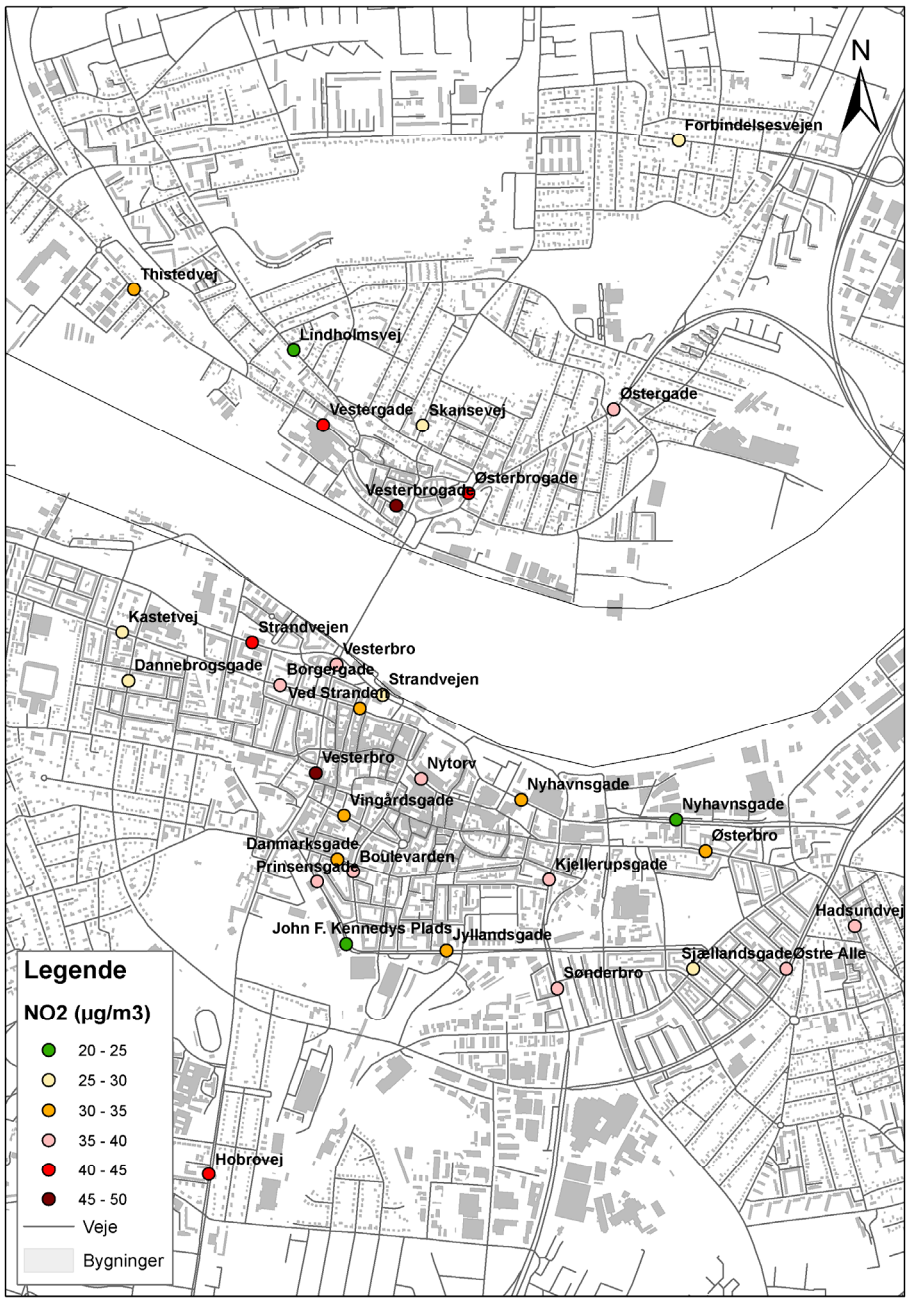



**Figure 3.8.** Map showing the location of the selected streets in Aalborg and the annual mean concentrations of $NO_2$ for 2009. The contribution from traffic in the street canyons is calculated with the street canyon model OSPM. The urban background is obtained from calculations with the urban background 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/m$^3$ $NO_x$ calculated as $NO_2$ for the calendar year. The limit value is based on EU Directive 2008/507EC (EC, 2008). The results from the model calculations show (Figure 3.9) that the annual mean concentrations of $NO_x$ were below the limit value in 2009. The only exception from this is for Copenhagen; however, the limit value for protection of vegetation is only valid outside agglomerations. Figure 3.10 shows that the modelled annual mean NOx concentration is in acceptable agreement with the measurements. The

underestimation by the model is most likely due to insufficient spatial resolution of the model (6 km x 6 km).

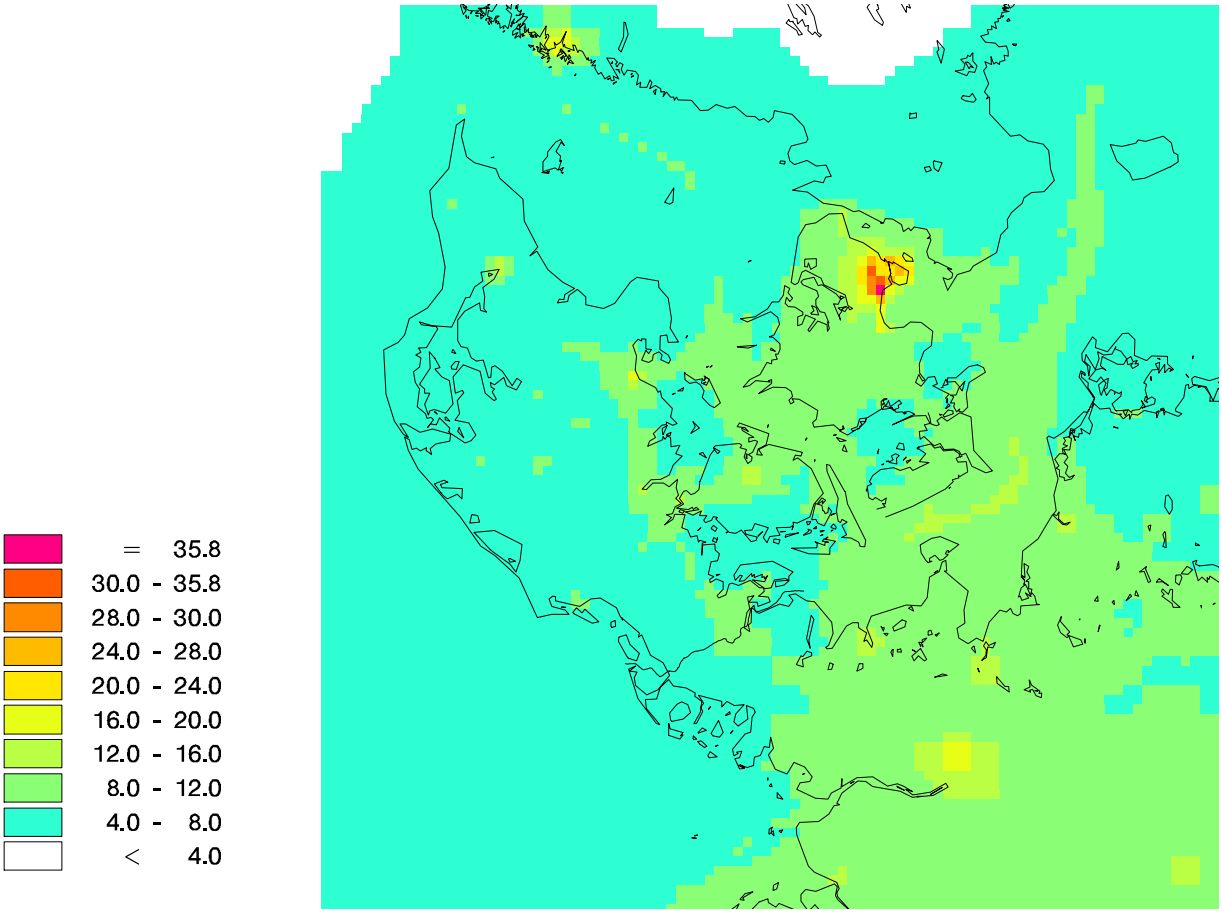



**Figure 3.9.** Annual mean concentrations of $NO_x$ for 2009 calculated with DEHM given as $\mu g/m^3$, when all $NO_x$ is calculated as $NO_2$. The figure shows the average concentrations for the 5.6 km x 5.6 km grid cells used in the model.

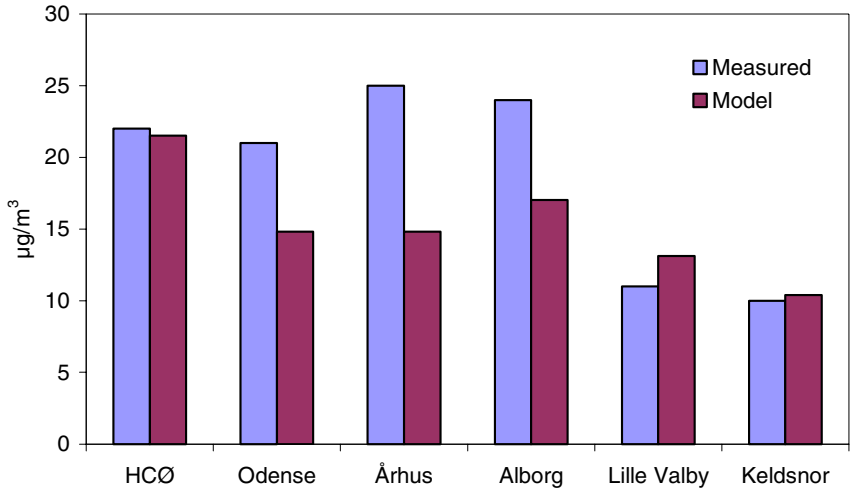



**Figure 3.10.** Annual mean concentrations of $NO_x$ for 2009 as measured at urban and rural background stations and as modelled using DEHM.

# 4 Ozone

## 4.1 Annual statistics

**Table 4.1.** *Ozone* ($O_3$) 2009. All parameters are calculated with 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 2008/50/EC (EC, 2008).

| 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 | 7865 | 54 | 54 | 122 | 100 | 134 | 5340 |
| Århus/6159 | 7419 | 49 | 50 | 117 | 91 | 125 | 3098 |
| Odense/9159 | 7915 | 52 | 52 | 136 | 99 | 151 | 5672 |
| Aalborg/8158 | 8016 | 52 | 54 | 123 | 94 | 134 | 4538 |
| *Rural* | | | | | | | |
| Lille Valby/2090 | 7853 | 57 | 57 | 125 | 104 | 138 | 6719 |
| Keldsnor/9055 | 6874 | 58 | 59 | 124 | 99 | 133 | 4665 |
| *Traffic* | | | | | | | |
| Copenhagen/1257 | 8002 | 38 | 38 | 103 | 77 | 111 | 658 |
| Copenhagen/1103 | 7445 | 34 | 33 | 90 | 71 | 106 | 64 |
| Target value | >7154 | - | - | - | 120 | - | 18 000 |
| Long term objective | >7154 | - | - | 120 | - | - | 6 000 |

The maximum 8 hours daily mean value must not exceed 120 µg/m$^3$ more than 25 days per calendar year averaged over three years. This target value was not exceeded for 2007-2009 at any of the stations.

The target values and long term objectives are given in the EU Directive 2008/50/EC (EC, 2008).

Number of information to the public due to exceedance of the information threshold (180 µg/m$^3$) in 2009: 0.

Number of information to the public due to exceedance of the alert threshold (240 µg/m$^3$) in 2009: 0.

## 4.2 Trends

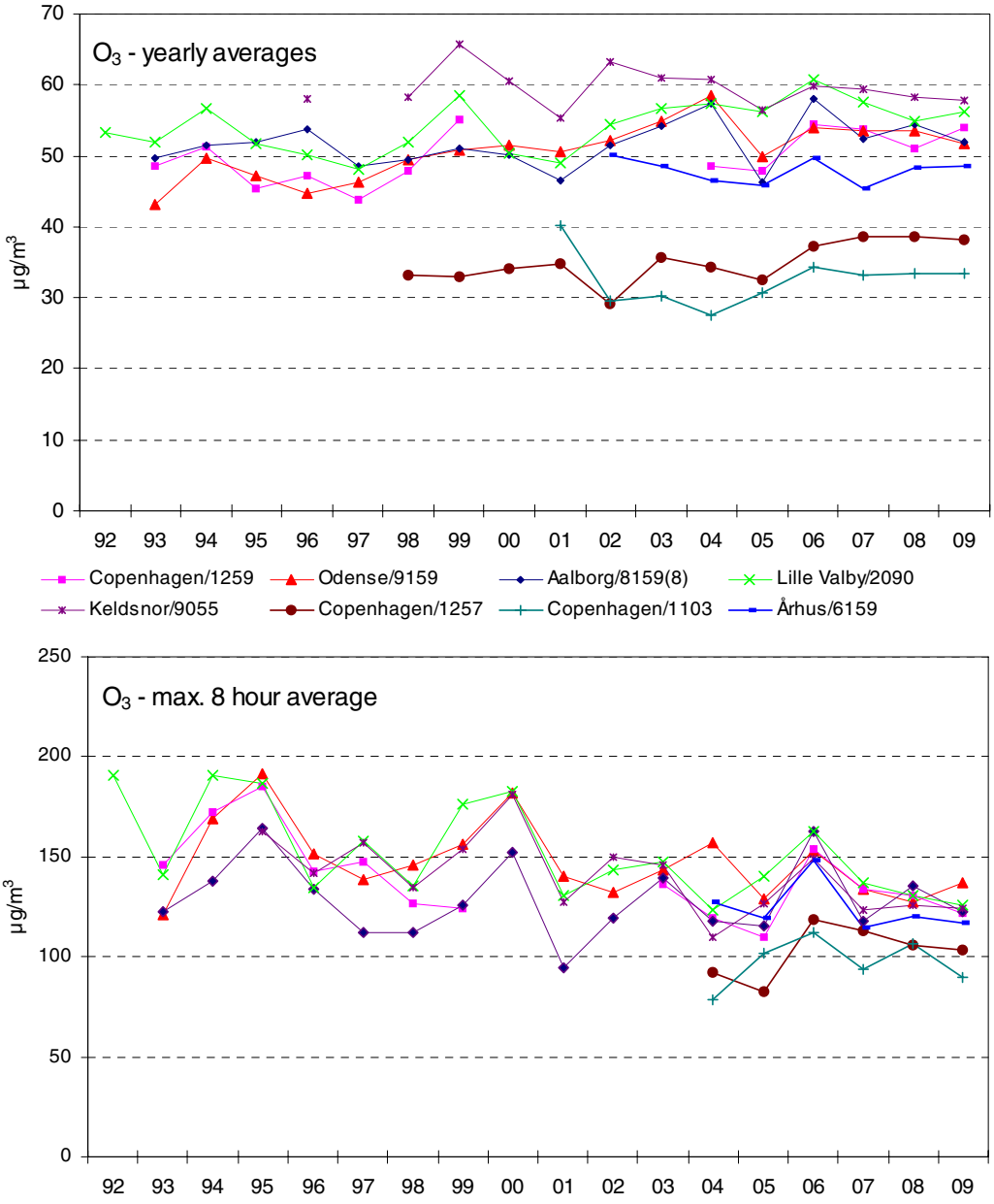



**Figure 4.1** Annual average values and the max. 8 hour average value. The latter is calculated as hourly 8 hour running averages according to the provisions in the EU Directive (EC, 2008). Previous results from Copenhagen/1103 can be found at the Website of the Copenhagen Environmental Protection Agency (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 during 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 Directive (EC, 2008). Results from the model calculations for 2009 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, 2008) 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 2009. The model calculations similarly show that the one hour mean concentration did not exceed 180 µg/m$^3$ in 2009 (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 of ozone precursors 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 increase the area where the long term objective for ozone was exceeded in 2009.

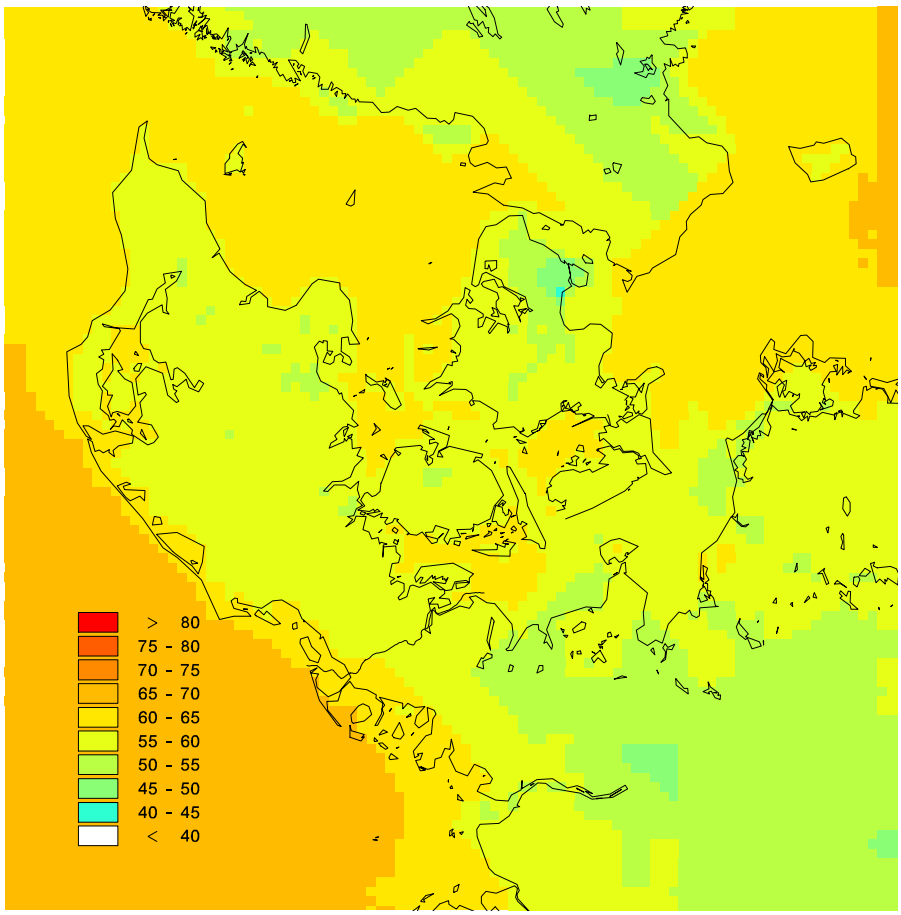
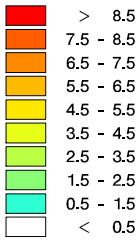



**Figure 4.2.** Annual mean concentrations of $O_3$ (µg/m$^3$) for 2009 calculated using DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model.



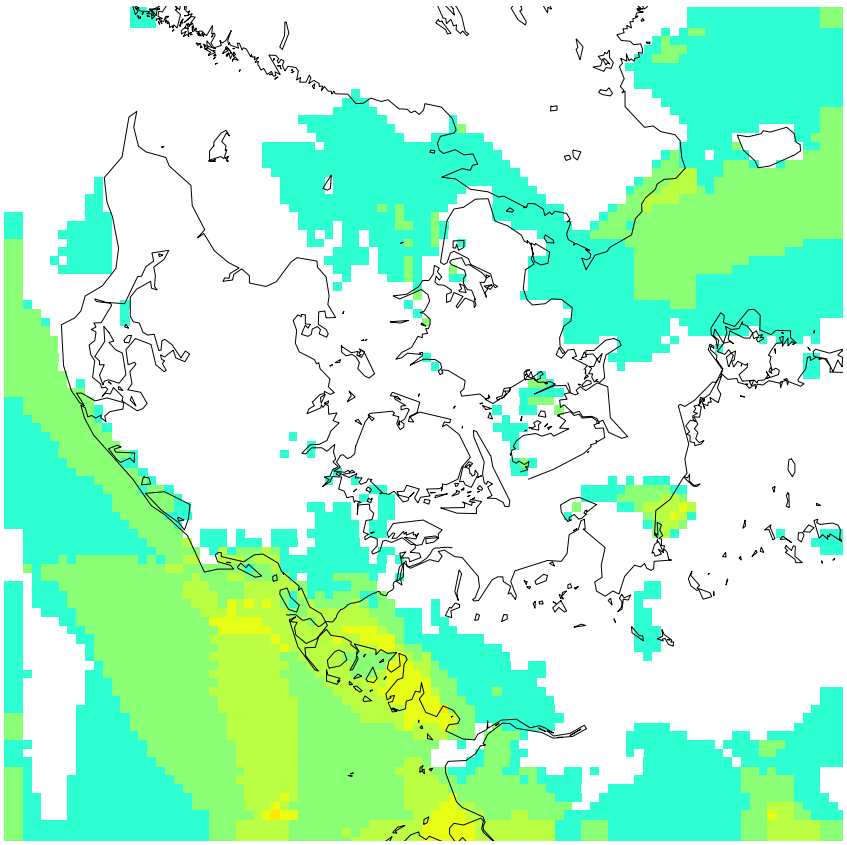
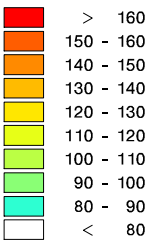



**Figure 4.3.** Number of exceedances of 120 µg/m$^3$ for 8-hour running mean concentrations of ozone in 2009. The calculations were carried out using DEHM.



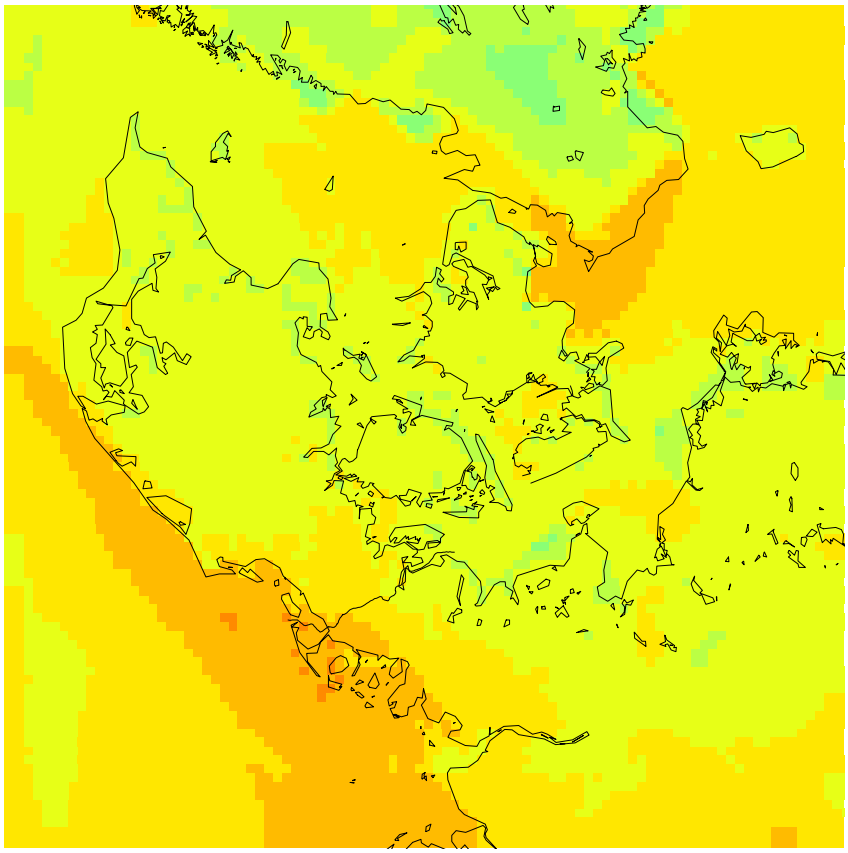



**Figure 4.4.** Maximum 8 hour running mean concentration (µg/m$^3$) of ozone in 2009 calculated using DEHM.

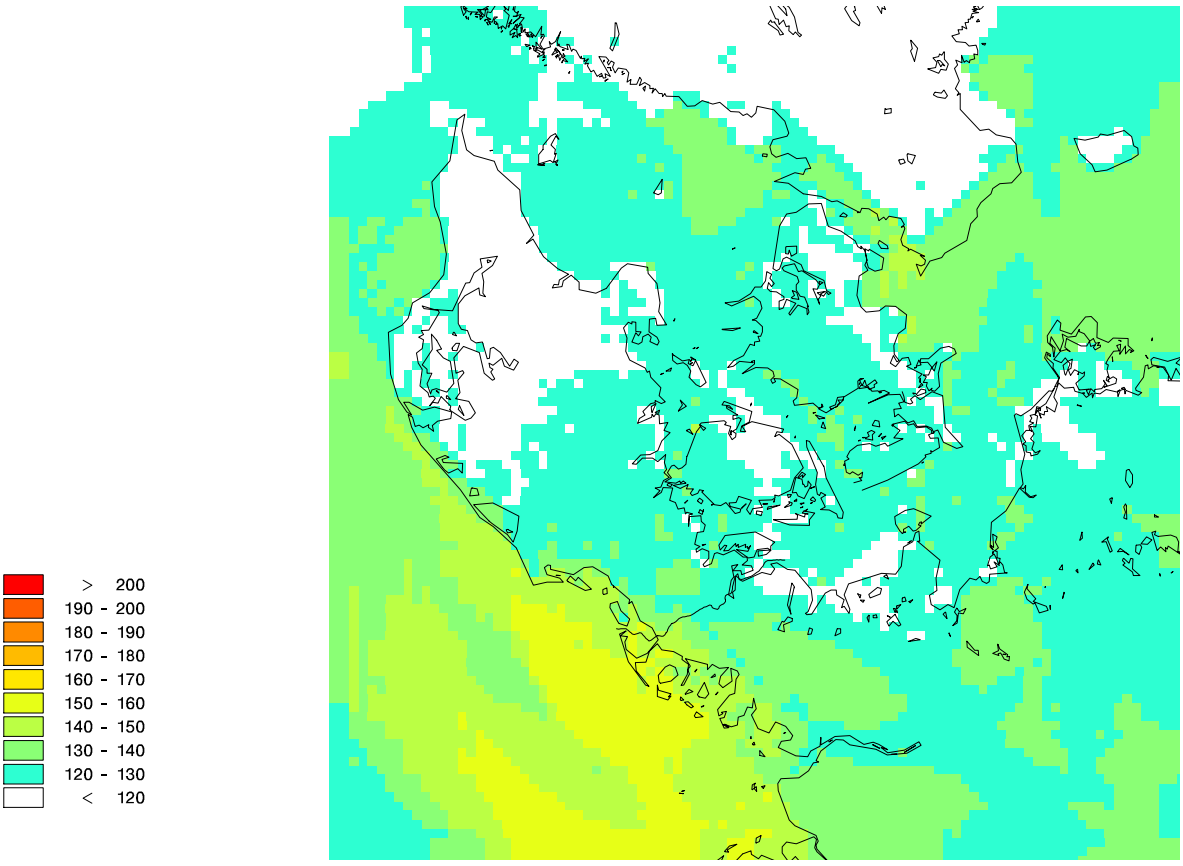



**Figure 4.5.** Maximum one hour mean concentration of ozone (µg/m3) in 2009 calculated using DEHM.

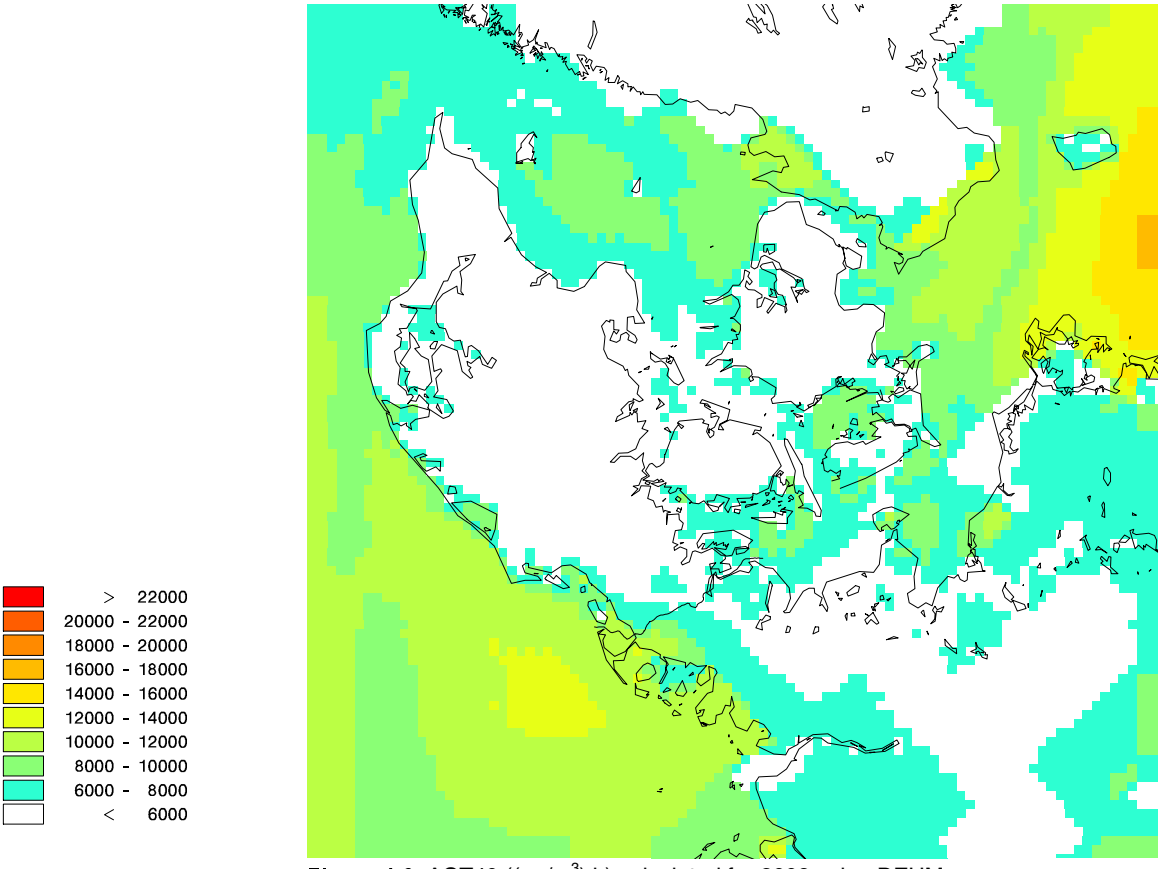



**Figure 4.6.** AOT40 ((µg/m$^3$)·h) calculated for 2009 using DEHM.

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 period from 8:00 to 20:00 over season 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 Directive 2008/50/EC (EC, 2008). The results from the model calculations for 2009 using DEHM (Figure 4.6) show that AOT40 was below the target value for the entire country. The long term objective was exceeded for minor parts of the country; mainly at coastal areas.

# 5 Carbon monoxide

## 5.1 Annual statistics

**Table 5.1.** Annual statistics for carbon monoxide (CO) in 2009. 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 | 8070 | 491 | 424 | 1275 | 1970 | 1844 | 3179 |
| Copenhagen/1103 | 5647 | 509 | 463 | 1105 | 1796 | 2000 | 2770 |
| Århus/6153 | 8283 | 341 | 300 | 791 | 1227 | 1223 | 1508 |
| Odense/9155 | 7459 | 471 | 383 | 1254 | 1928 | 1826 | 2681 |
| Aalborg/8151 | 8163 | 499 | 454 | 1130 | 1654 | 1640 | 1923 |
| *Urban Background:* | | | | | | | |
| Copenhagen/1259 | 7438 | 229 | 213 | 489 | 678 | 689 | 1220 |
| *Rural* | | | | | | | |
| Lille Valby/2090 | 7808 | 210 | 210 | 415 | 564 | 562 | 806 |
| EU Limit value | - | - | - | - | - | 10 000 | - |
| WHO Guideline values | - | - | - | - | - | 10 000 | 30 000 |

The limit value is based on EU Directive 2008/50/EC (EC, 2008).

The guideline values are proposed by WHO (2000).

## 5.2 Trends

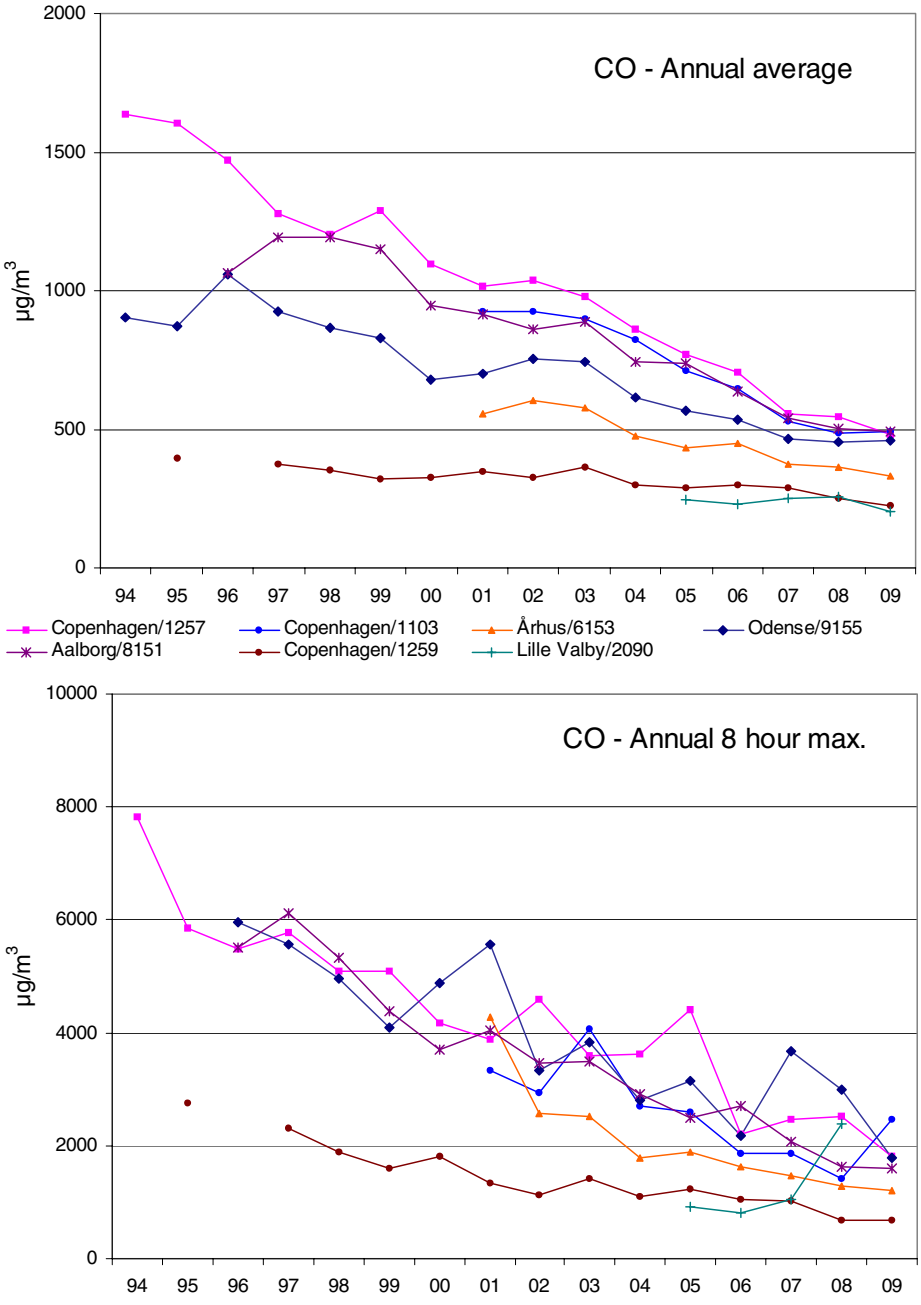



**Figure 5.1.** Annual average values and highest 8-hour value calculated based on an hourly moving average. Previous results from Copenhagen/1103 can be found at the website of the Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk).

# 6 Benzene and Toluene

Benzene and toluene are measured on two street stations in Copenhagen, Jagtvej/1257 and H.C. Andersens Boulevard/1103, using a passive sampling method with weekly averages.

## 6.1 Annual statistics

**Table 6.1.** Annual statistics for Benzene in 2009. The values are based on weekly averages.

| Unit: µg/m$^3$ | Number of results | Average | Max weekly average |
|---|---|---|---|
| Copenhagen/1103 | 47 | 1.5 | 2.5 |
| Copenhagen/1257 | 51 | 1.4 | 3.0 |
| Limit value | | 5 | |

The limit value is based on EU Directive 2008/50/EC (EC, 2008).

**Table 6.2.** Annual statistics for Toluene in 2009. The Maximum weekly average is the maximum value for the weekly measurements (WHO, 2000).

| Unit: µg/m$^3$ | Number of results | Average | Max weekly avarage |
|---|---|---|---|
| Copenhagen/1103 | 47 | 4.7 | 6.3 |
| Copenhagen/1257 | 51 | 4.0 | 7.3 |
| Guideline value | - | - | 260 |

The guideline value is established by WHO (WHO, 2000).

## 6.2 Trends

Benzene has decreased from approximately 4 µg/m³ in the beginning of this millennium to a value below the lower assessment threshold of 2 ug/m3 (EC, 2008), that is annual averages of 1.4 and 1.5 µg/m³ on the two urban street stations in Copenhagen. Toluene shows a similar trend and annually averages of 4.7 and 4.0 µg/m³ on the urban street stations HCAB, Copenhagen/1103 and Jagtvej, Copenhagen/1257, respectively. The main reasons for the significant decreases of benzene and toluene are reductions of the emissions from traffic due to increased use of catalysts and higher ratio of diesel cars.

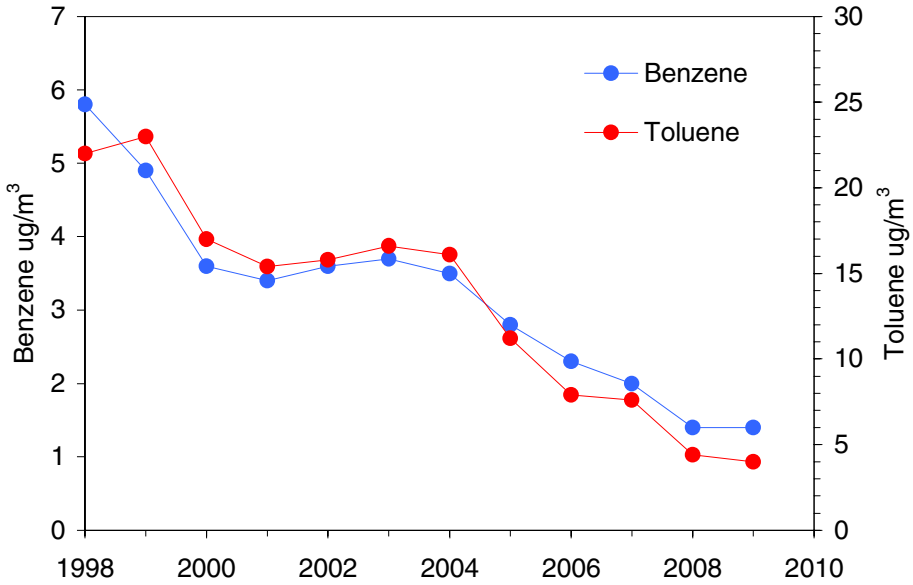



**Figure 6.1.** Annual average concentrations of benzene and toluene on the street station Jagtvej, Copenhagen/1257.

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

## 7.1 PM measurements

The limit values are based on the EU Directive 2008/50/EC (EC, 2008).

The SM200 sampler manufactured by OPSIS, Sweden, has been used in Denmark to measure $PM_{10}$ in accordance with the EU Directive (EC, 1999, 2008). 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 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 the internet.

Results indicate that the β-ray results from the SM200 sampler comply better with the reference method for $PM_{10}$ given in the EU 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 36th 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 using SM200-monitors (Table 7.1 and 7.2). 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 have a time resolution of 30 minutes (Table 7.3). During sampling the collected particles are heated to 50°C. At that temperature some of the volatile compounds 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 considerable uncertainty.

Due to technical problems with the sample inlet of the SM200-monitors only 116 diurnal values for $PM_{10}$ were measured at the station Copenhagen/1103 (HCAB). The annual average based on these measurements is therefore not representative for the full year. However, based on the TEOM measurements of $PM_{10}$ at the same measurement station and the measurements at Copenhagen/1259 (HCØ) it is possible to calculate an estimate of $PM_{10}$ for the time periods where data is lacking. This estimate is described in detail in Appendix 2. The numbers given for Copenhagen/1103 (HCAB) in table 7.1 is based on both measurements with SM200 and corrected TEOM-data.

Several of the SM200-monitors for measurements of $PM_{2.5}$ had the same technical problems as observed for the $PM_{10}$ instrument at Copenhagen/1103. The instruments at Copenhagen/1259, Aalborg/8151, Århus/6159 and Lille Valby/2090 all were subject to the technical problems, and it has been necessary to reject a considerable amount of measurement data. Data from these stations are therefore not representative for the full calendar year. The problem was solved in December 2009.

**Table 7.1.** Annual statistics for $PM_{10}$ in 2009. All parameters are calculated as diurnal averages at ambient temperature and pressure.

| Unit µg/m$^3$ | Number of results | Average | Median | 36.highest result | 90 percentile | Max. day |
|---|---|---|---|---|---|---|
| *Traffic* | | | | | | |
| Copenhagen/1257 | 330 | 29 | 27 | 45 | 45 | 85 |
| Copenhagen/1103 **) | 229 | 30 | 29 | 42 | 43 | 126 |
| Århus/6153 | 365 | 25 | 24 | 36 | 35 | 80 |
| Odense/9155 | 337 | 27 | 26 | 41 | 42 | 76 |
| *Urban background* | | | | | | |
| Copenhagen/1259 | 347 | 21 | 19 | 31 | 31 | 58 |
| *Rural* | | | | | | |
| Lille Valby/2090 | 347 | 17 | 16 | 27 | 27 | 48 |
| Keldsnor/9055 | 342 | 18 | 16 | 29 | 29 | 67 |
| 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 2009. All parameters are calculated as diurnal averages at ambient temperature and pressure. The limit values shall be met in 2015.

| Unit µg/m$^3$ | Number of results | Average | Median | 90 percentile | Max. day |
|---|---|---|---|---|---|
| *Traffic* | | | | | |
| Copenhagen/1103 | 343 | 18 | 17 | 28 | 53 |
| Århus/6153 | 355 | 14 | 13 | 25 | 58 |
| Aalborg/8151 | 149 | 23 | 22 | 37 | 58 |
| *Urban background* | | | | | |
| Copenhagen/1259 | 258 | 11 | 10 | 19 | 40 |
| Århus/6159 | 130 | 17 | 16 | 29 | 39 |
| Aalborg/8158 | 346 | 15 | 13 | 25 | 53 |
| *Rural* | | | | | |
| Lille Valby/2090 | 94 | 14 | 12 | 22 | 36 |
| Limit value (2015) (parenthesis gives proposed value for 2020) | >329 | 25(20) | | | |

**Table 7.3.** Annual statistics for $PM_{10}$ measured in 2009 using TEOM. The values are calculated based on diurnal averages.

| Unit µg/m$^3$ | Number of results | Average | 36$^{th}$ highest result | 90 percentile | Average × 1.3 | 36$^{th}$ highest × 1.3 |
|---|---|---|---|---|---|---|
| *Traffic* | | | | | | |
| Copenhagen/1103 | 323 | 26 | 36 | 36 | 33 | 46 |
| *Urban background* | | | | | | |
| Copenhagen/1259 | 348 | 13 | 19 | 19 | 17 | 25 |
| Limit values | >329 | - | - | - | 40 | 50 |

**Table 7.4.** Annual statistics for $PM_{2.5}$ measured in 2009 using TEOM. The values are calculated based on diurnal averages.

| Unit µg/m$^3$ | Number of results | Average | 90 percentile | Average × 1.3 |
|---|---|---|---|---|
| *Traffic* | | | | |
| Copenhagen/1103 | 339 | 12 | 19 | 16 |
| *Urban Background* | | | | |
| Copenhagen/1259 | 346 | 9 | 15 | 12 |
| *Rural* | | | | |
| Lille Valby/2090 | 362 | 8 | 13 | 11 |
| Limit value (2015) (parenthesis gives proposed value for 2020) | >329 | 25(20) | | |

## 7.3 Trends

Up to the year 2000 the particulate matter was measured as Total Suspended Particulate matter (TSP) corresponding to particles with a diameter up to around 25 µm (Figure 7.1). The exact cut-off depended strongly on the wind velocity. From 2001 most of the measurements of particulate matter was changed from TSP to PM10 according to the EU directive adopted in 1999 (EC, 1999). $PM_{10}$ 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.

A major reduction (7 µg/m$^3$) in $PM_{10}$ concentration was observed at the measurement station HCAB (Copenhagen/1103) from 2008 to 2009. Detailed examination of all the measurements at HCAB showed that the main reason for this decrease was new asphalt surface on the road laid out during August and September 2008 (Ellermann et al., 2010) that significantly reduced dust generation from road abrasion.

The measurements of PM2.5 started in 2007 at Copgenhagen/1103 and at the other stations in 2008. Figure 7.3 presents all the results from measurements of $PM_{2.5}$ that are done so far. Measurements for 2008 and 2009 give a preliminary calculation of the average exposure indicator (EC, 2008) of about 13 µg/m$^3$ (the average exposure indicator is defined as the average urban background concentration measured at Copenhagen/1259, Århus/6159 and Aalborg/8158). Further analysis of the effect of the lacking $PM_{2.5}$ data in 2009 in respect to establishing an average exposure indicator will be presented in next years report, when data from 2010 also is available.

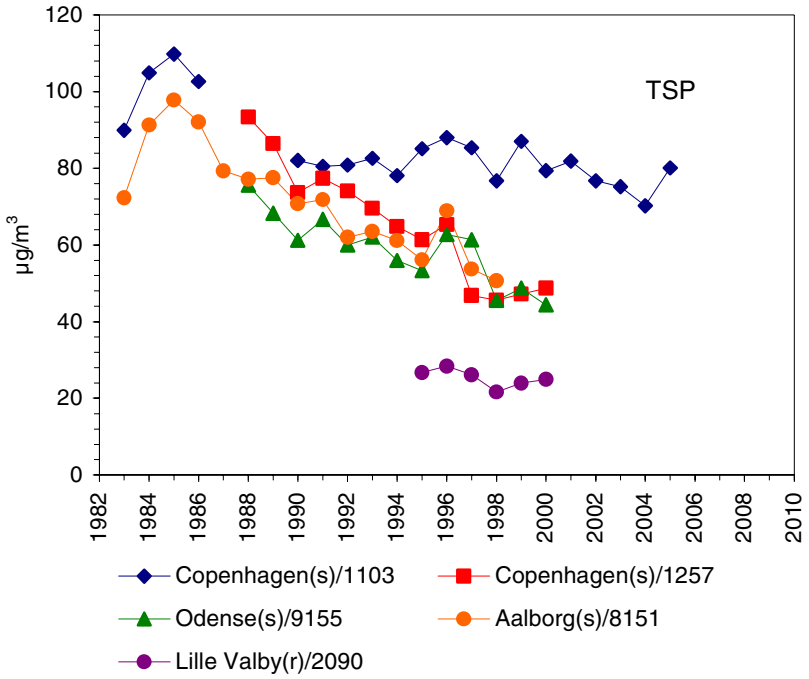



**Figure 7.1.** Annual averages for TSP measured at street stations (s) and at rural background station (r).

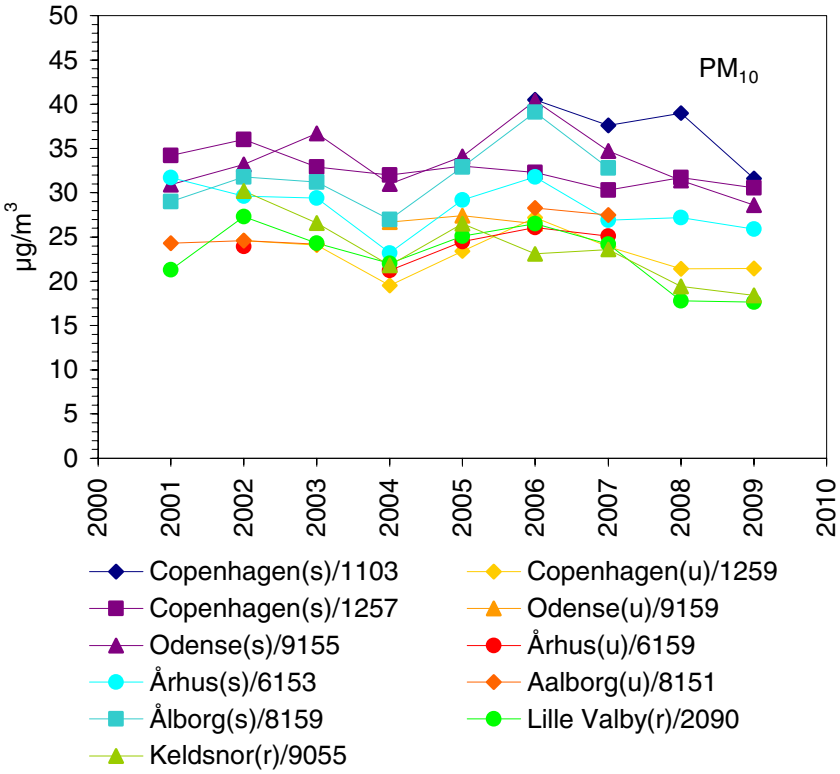



**Figure 7.2.** Annual averages for $PM_{10}$ measured at street stations (s), urban background stations (u) and at rural background stations (r). The change from gravimetric determination to the use of β-measurements from 2006 gives rise to a 5-10% increase due to the shift of method. The value for $PM_{10}$ at Copenhagen/1103 in 2008 and 2009 is based on the measurements with SM200 and the estimate described above. Data are given at standard temperature and pressure (0ºC and 1 atm.). The difference between ambient temperature and pressure and standard temperature and pressure is – 3% on the annual average.

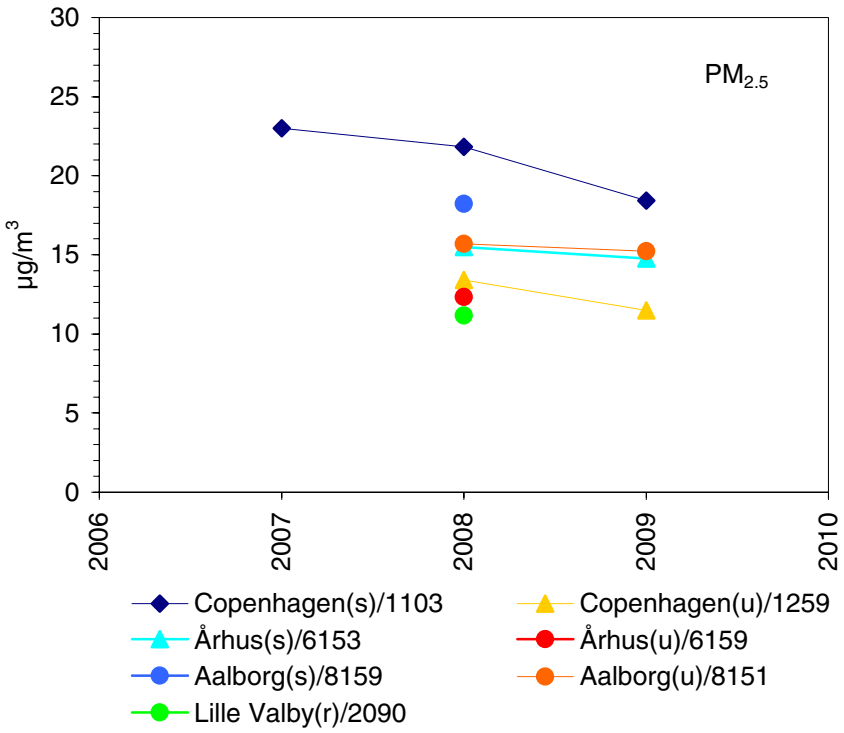



**Figure 7.3.** Annual averages for $PM_{2.5}$ measured at street stations (s), urban background stations (u) and at rural background station (r). Only annual averages covering more than 2/3 of the years are shown. Data are given at standard temperature and pressure (0ºC and 1 atm.). The difference between ambient temperature and pressure and standard temperature and pressure is – 3% on the annual average.

# 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 8.1).

The PIXE analysis provides the measurements obligatory according to EU Directive 2004/107/EC (EC, 2005) for As, Cr and Ni and EU Directive 2008/50/EC (EC, 2008) for Pb. 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 agreed that the Swedish measurements at Röå (Table 8.2) can fulfil the Danish obligations on measurements of Hg. This agreement is based on the fact that the spatial variation of background Hg concentrations is very small.

## 8.2 Annual statistics

In 2009 there were technical problems with the sampling system at Copenhagen/1103 for $PM_{10}$ and at Århus/6153, Copenhagen/1259 and Lille Valby/2090 for $PM_{2.5}$. The averages given in table 8.1 for these stations may therefore not be representative for the full year 2009.

**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 2009 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. The number in parenthesis after the station name gives the number of diurnal measurements for the station.

| Unit: ng/m$^3$ | V | Cr | Mn | Ni | Cu | Zn | As | Se | Cd | Pb |
|---|---|---|---|---|---|---|---|---|---|---|
| ***PM10, Traffic*** | | | | | | | | | | |
| Copenhagen/1257 (337) | 3.6 | 5,9 | 14.4 | 3.7 | 63.1 | 36.8 | 0.5 | 0.3 | < 1.5 | 5.3 |
| Copenhagen/1103 (117) | 2.3 | 7.5 | 16.1 | 2.9 | 65.3 | 33.3 | 0.6 | 0.3 | < 1,5 | 6.3 |
| Århus/6153 (358) | 3.7 | 4.2 | 10.1 | 4.2 | 38.9 | 27.9 | 0.5 | 0.4 | < 1.5 | 4.6 |
| ***PM10, Urban background*** | | | | | | | | | | |
| Copenhagen/1259 (356) | 3.2 | 1,0 | 4.8 | 2.9 | 10.3 | 14.9 | 0.4 | 0.3 | < 1.5 | 3.8 |
| ***PM10, Rural*** | | | | | | | | | | |
| Lille Valby/2090 (352) | 2.4 | 1.0 | 3.1 | 1.8 | 4.3 | 11.4 | 0.5 | 0.4 | < 1.5 | 3.8 |
| ***PM2.5, Traffic*** | | | | | | | | | | |
| Copenhagen/1103 (341) | 2.9 | 1 | 3.3 | 1.9 | 12.3 | 15.1 | 0.4 | 0.3 | < 1.5 | 3.5 |
| Århus/6153 (350) | 2.8 | < 1 | 1.3 | 2,8 | 5.1 | 13.9 | 0.4 | 0.3 | < 1.5 | 3.3 |
| ***PM2.5, Urban background*** | | | | | | | | | | |
| Copenhagen/1259 (192) | 2.8 | < 1 | 0.9 | 1.7 | 4.9 | 24.9 | 0.4 | 0.3 | < 1.5 | 3.3 |
| Århus/6159 (126) | 3.1 | < 1 | 1.3 | 3,3 | 3.9 | 9.8 | 0.6 | 0.4 | < 1.5 | 4.2 |
| ***PM2.5, Rural*** | | | | | | | | | | |
| Lille Valby/2090 (96) | 1.9 | < 1 | 0.8 | 1.3 | 1.5 | 8.0 | 0.6 | 0.3 | < 1.5 | 3.6 |
| EU Target (limit) Values | | | | 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). The limit value for Pb is found in EU Directive 2008/50/EC (EC, 2008). The guidelines and life time risk for the carcinogenic metals are established by WHO (WHO, 2000).

**Table 8.2.** Annual statistics for Mercury 2009. Measured at Rööå in southern Sweden by the Swedish Environmental Research Institute (http://www.ivl.se/english/ivlstartpage/leftmenu/environmentaldata/ metalsi-nairandprecipitation.106.360a0d56117c51a2d30800064440.html).

| Unit: ng/m3 | Total Gas Hg (ng/m3) | Total Particles Hg (ng/m3) |
|---|---|---|
| Rööå (SEOOO14) | 1.5 | 0.009 |

## 8.3 Trends

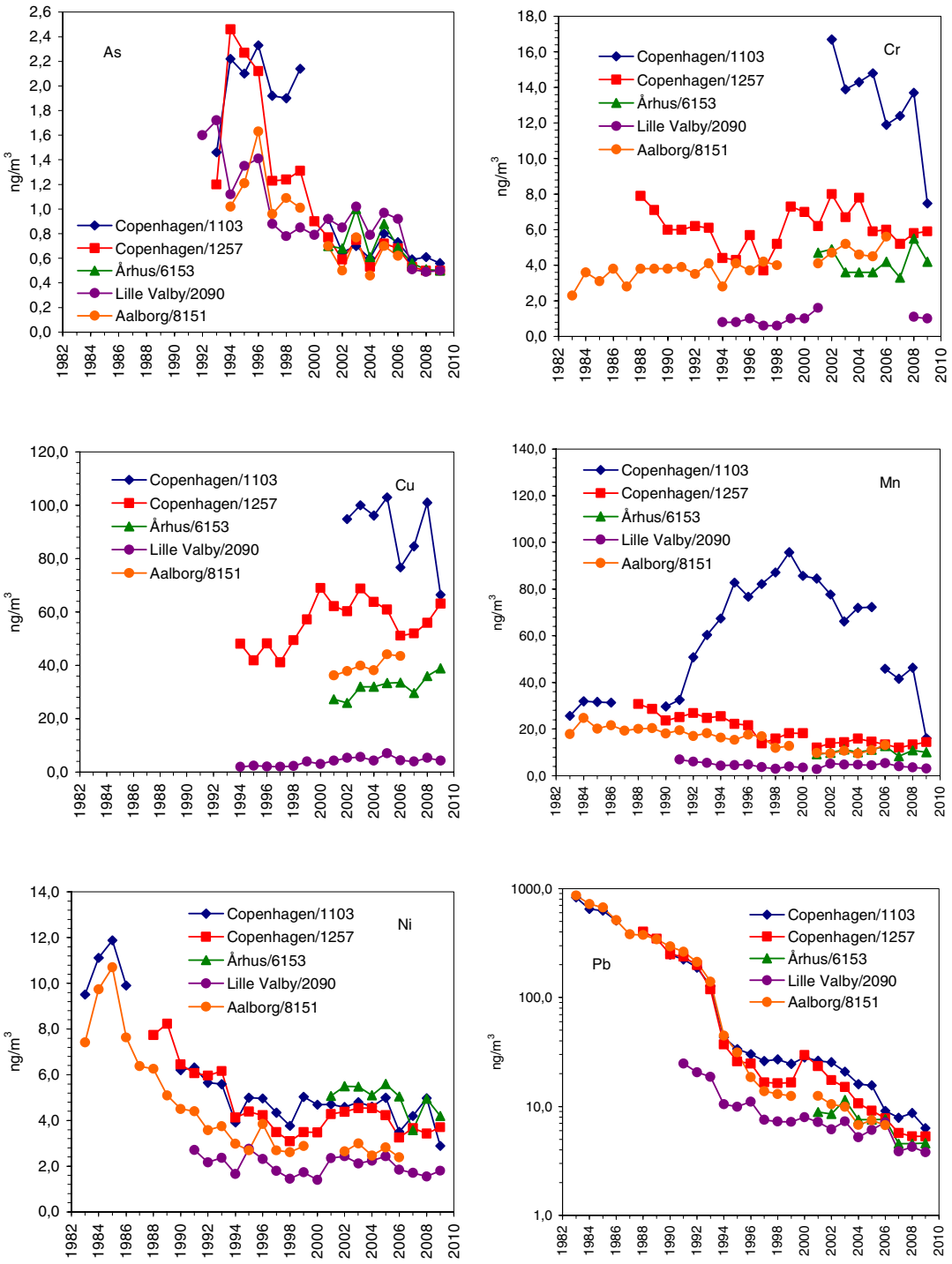



**Figure 8.1.** Annual averages from selected stations for some heavy metals in particulate matter. Until 2000 in TSP and later in $PM_{10}$ – except for Copenhagen/1103 where $PM_{10}$ replaced TSP from the beginning of 2006. The heavy metals are usually found in fine particles, which make the TSP and the $PM_{10}$ values comparable. This is despite Mn, where a significant reduction of Mn was observed when the sampling was changed from TSP to $PM_{10}$ in 2000 and 2006 (1103).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 astfalt at H. C. Andersens Boulevard. The increase in Cu (especially at Copenhagen/1257), 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 2009. 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 | 4th highest diurnal mean |
|---|---|---|---|---|---|---|---|
| Traffic | | | | | | | |
| Copenhagen/1103 | 7706 | 3.1 | 2.8 | 2.5 | 9.2 | 61 | 9 |
| Aalborg/8151 | 8702 | 2.8 | 2.9 | 2.1 | 9.8 | 33 | 6 |
| Limit values | >7467 | 20 | 20 | | | 350 | 125 |

The limit values are based on EU Directive 2008/50/EC (EC, 2008).

**Table 9.2.** Annual averages for particulate sulphur (S) measured in $PM_{10}$ in 2009. The sulphur containing particles are mainly present in sub-micron particles. Measurements are daily averages.

| Unit: µg(S)/m3 | Number of results | Average |
|---|---|---|
| Traffic | | |
| Copenhagen/1257 | 337 | 0.72 |
| Copenhagen/1103 | 117 | 0.72 |
| Århus/6153 | 358 | 0.70 |
| Urban background | | |
| Copenhagen/1259 | 356 | 0.60 |
| Rural | | |
| Lille Valby/2090 | 352 | 0.64 |

Due to technical problems with the sampling equipment only 117 daily results exist for Copenhagen/1103. The average is therefore not representative for the full year.

## 9.2 Trends

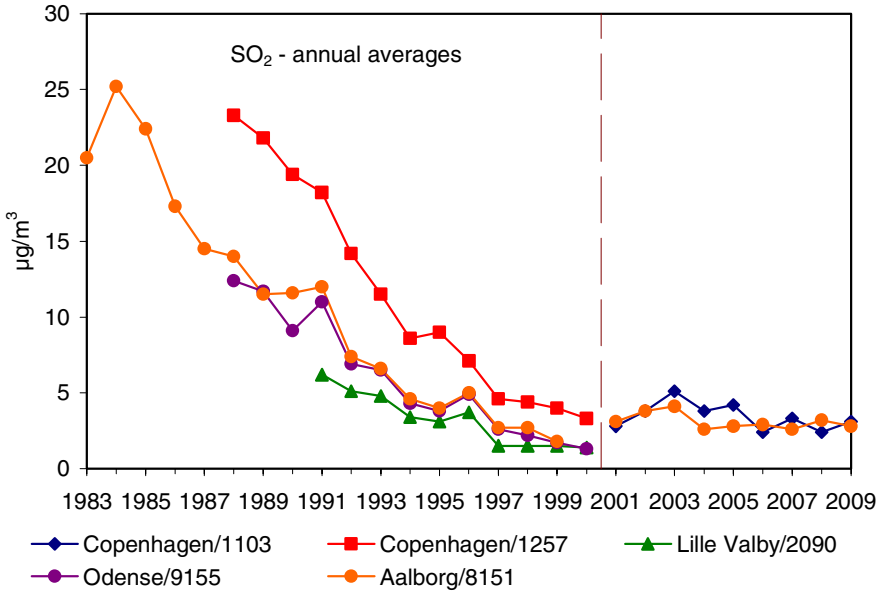



**Figure 9.1.** Annual averages for $SO_2$. Until 2001 the results were obtained using KOH impregnated filters for collection of $SO_2$. These measurements ceased in 2000. After 2000 the $SO_2$ measurements have been carried out using $SO_2$-monitors in order to monitor episodic results. The detection limit for the monitors is a few µg/m$^3$, which makes the average and median values encumbered with high relative uncertainties. The shift in level from 2000 to 2001 is due to shift of the methods.

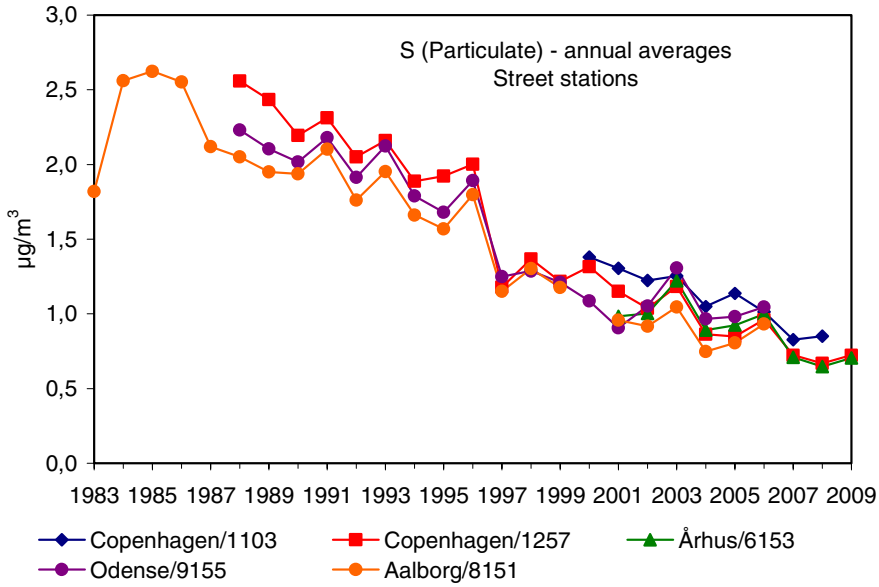



**Figure 9.2.** Annual averages for particulate sulphur at street stations. The particulate sulphur from 2000 and earlier is determined in TSP samples. From 2001 results are from $PM_{10}$ samples – except for Copenhagen/1103, where TSP measurements are continued until 2005. The sulphur containing particles are mainly present in sub-micron particles, which makes the TSP and $PM_{10}$ results comparable.

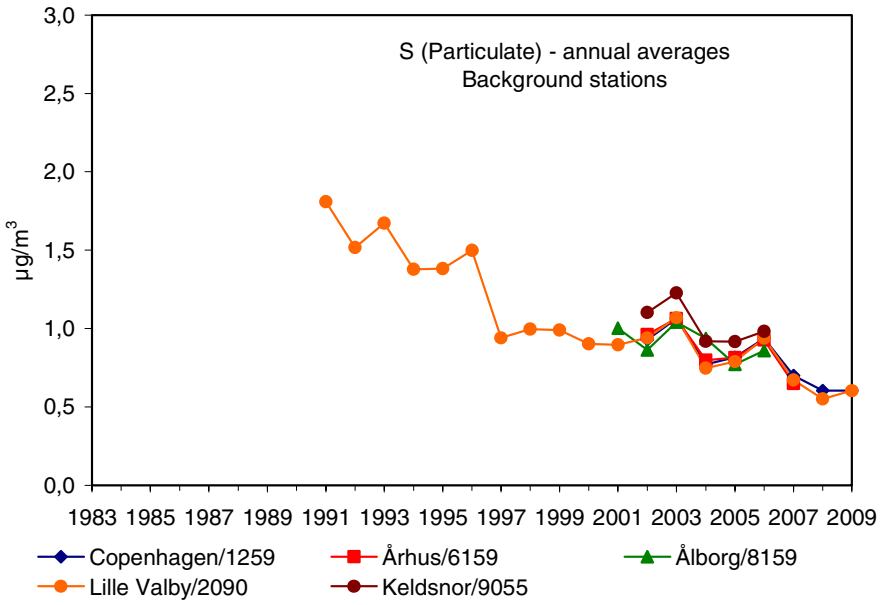



**Figure 9.3.** Annual averages for particulate sulphur at urban background and rural stations. The particulate sulphur from 2000 and earlier is determined in TSP samples. From 2001 results are in analyzed using $PM_{10}$ samples. The sulphur containing particles are mainly present in sub-micron particles, 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 2008/50/EC (EC, 2008). The results from the model calculations using DEHM show that the annual and winter mean concentrations of $SO_2$ in 2009 (Figure 9.4 and 9.5) are well below the limit value.

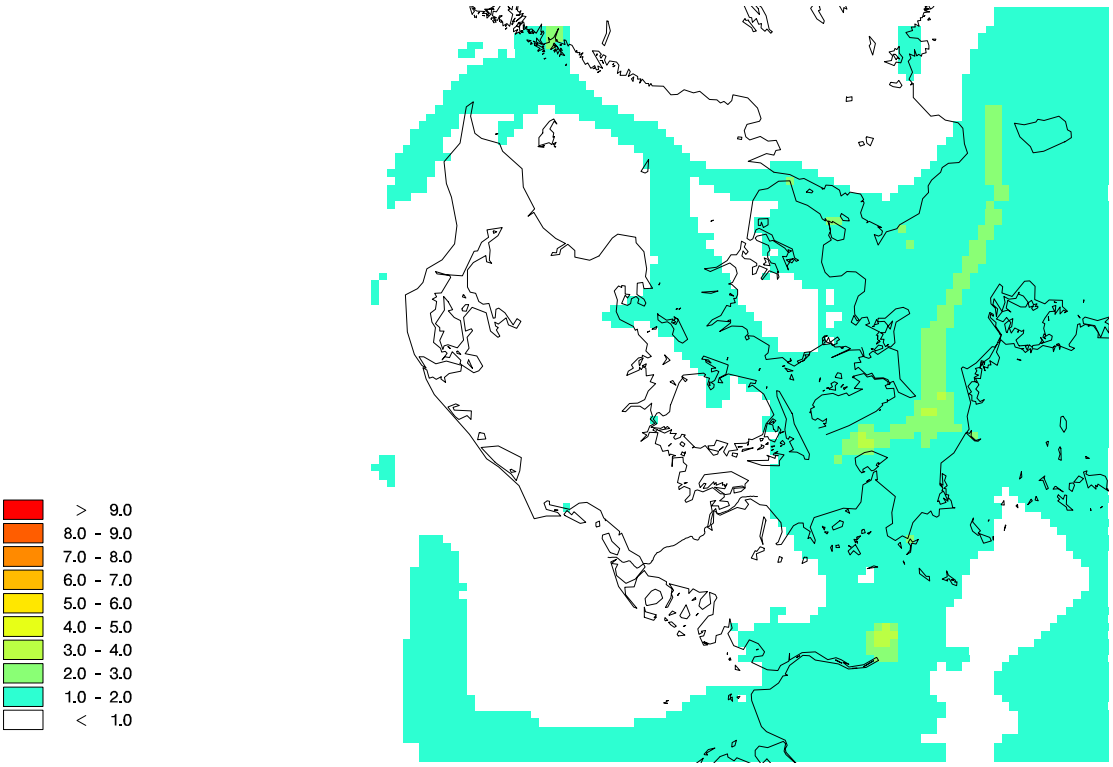



**Figure 9.4.** Annual mean concentrations of $SO_2$ (µg/m$^3$) for 2009 calculated with DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model. The higher concentrations calculated for the inner Danish waters are due to emissions from ships.

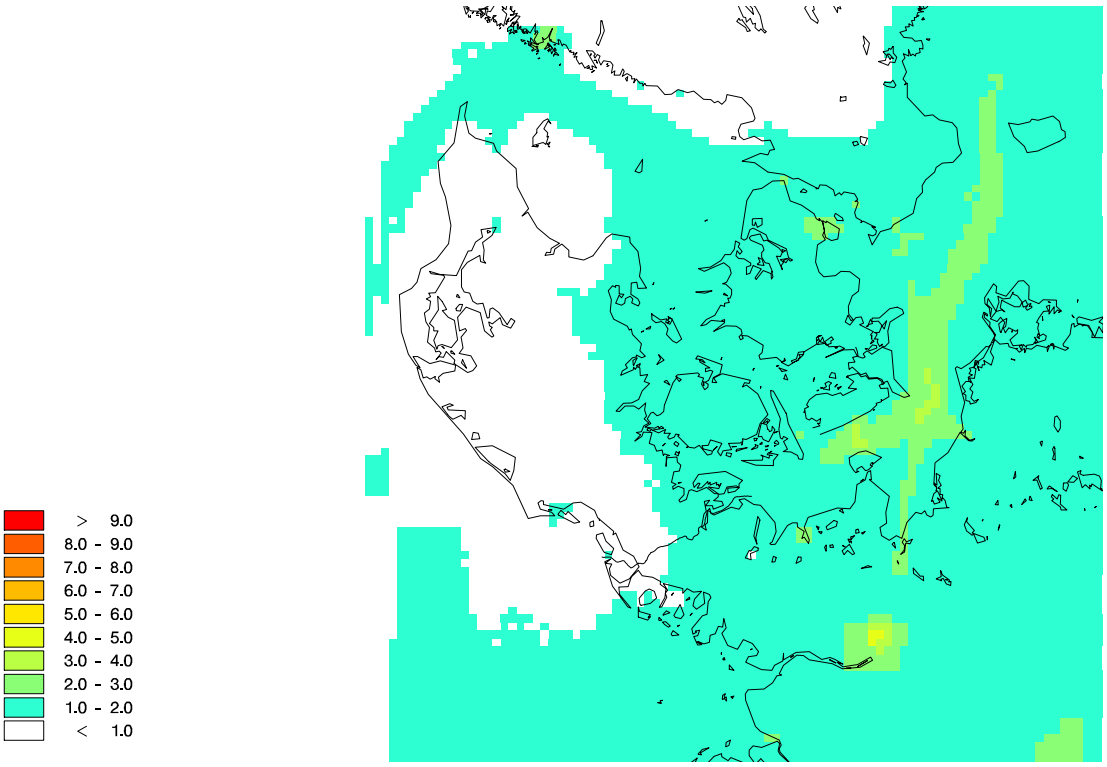



**Figure 9.5.** Winter mean concentrations of $SO_2$ (µg/m$^3$) for 2009 calculated with DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model. The high concentrations calculated for the inner Danish waters are due to emissions from ship traffic.

# 10 Polyaromatic Hydrocarbons (PAHs)

Following the EU Directive 2004/107/EC (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 12 PAHs are analyzed in the method.

## 10.2 Results

There are available data starting from the end of February, as the high volume sampling was not functioning. The average concentration of benzo[a]pyrene measured in Copenhagen was 0.25 ng/m$^3$ in 2009. 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, 0.20 ng/m$^3$; benzo[b]fluoranthene, 0.47 ng/m$^3$; benzo[j+k]fluoranthenes, 0.18 ng/m$^3$; indeno[1,2,3-cd]pyrene, 0.30 ng/m$^3$; dibenzo[a,h]anthracene 0.06 ng/m$^3$. It should be noticed that the annual average values are slightly lower than in 2008. This is most probably due to the fact that the contribution of two winter months (January and February) is missing. Since PAH concentrations are relatively higher in winter, the lack of these data has contributed to lower average annual values of PAH concentrations.

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 2009

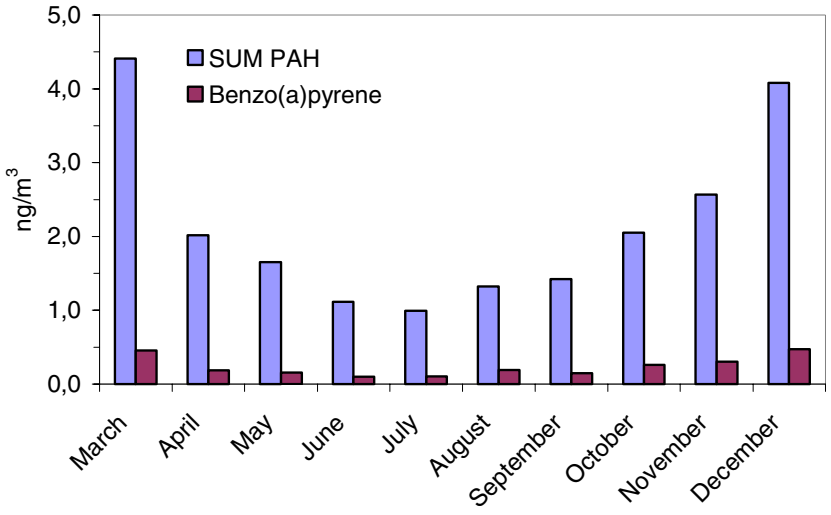



**Figure 10.1.** Monthly average concentrations in 2009 of benzo[a]pyrene and the sum of the analysed PAH.

**Table 10.1.** Daily minimum, maximum and average monthly concentrations (ng/m$^3$) of benzo[a]pyrene during 2009.

| Month | Minimum conc. | Maximum conc. | Average conc. |
|---|---|---|---|
| March | 0.15 | 1.4 | 0.46 |
| April | 0.13 | 0.29 | 0.19 |
| May | 0.04 | 0.68 | 0.16 |
| June | 0.02 | 0.28 | 0.10 |
| July | 0.02 | 0.18 | 0.10 |
| August | 0.09 | 0.42 | 0.19 |
| September | 0.06 | 0.37 | 0.15 |
| October | 0.05 | 0.51 | 0.26 |
| November | 0.08 | 1.1 | 0.30 |
| December | 0.19 | 2.0 | 0.47 |
| Annual | 0.02 | 2.0 | 0.25 |

# 11 Organic carbon and elemental carbon

Organic Carbon (OC) and Elemental Carbon (EC) are measured on H.C. Andersens Boulevard, Copenhagen/1103 and at Lille Valby/2090 in Roskilde approximately 30 km west of Copenhagen. Filter (quartz-behind-quartz) samples of ambient air are analyzed for OC and EC by a thermal/optical method according to the EUSAAR2 protocol. OC and EC are operationally defined.

## 11.1 Annual statistics

The measurements of Organis carbon (OC) and elemental carbon (EC) were initiated during the spring of 2009 with weekly time resolution, and were extended to daily resolution in autumn 2009. This change was made in order to decrease errors on the sampling of OC and EC. Weekly and daily concentrations are not directly comparable due to different sampling conditions.

The OC/EC ratio, and the absolute concentrations on the semirural background- and the urban street station differ markedly: EC is the major component at the urban street station (55% of total carbon), but account only for 26% in the rural background (Figure 11.1).

**Table 11.1.** Annual statistics for OC in 2009. The values are based on daily averages from 16.09.2009 (Copenhagen/1103) and 17.09.2009 (Lille Valby/2090) and onwards.

| Unit: ug/m$^3$ | Number of results | OC, average | Max. daily average |
|---|---|---|---|
| Copenhagen/ 1103 | 82 | 2.0 | 7.1 |
| Lille Valby/ 2090 | 94 | 1.0 | 3.7 |

**Table 11.2.** Annual statistics for EC in 2009. The values are based on daily averages from 16.09.2009 (Copenhagen/1103) and 17.09.2009 (Lille Valby/2090) and onwards.

| Unit: ug/m$^3$ | Number of results | EC, average | Max. daily average |
|---|---|---|---|
| Copenhagen 1103 | 82 | 2.4 | 6.6 |
| Lille Valby/ 2090 | 94 | 0.4 | 1.0 |

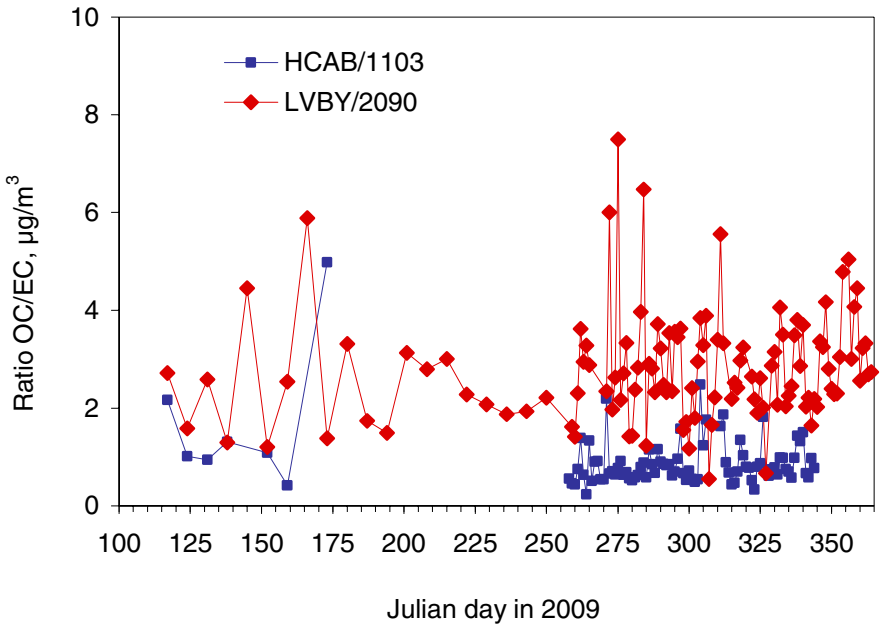



**Figure 11.1.** The ratio between organic carbon and elemental carbon, OC/EC, on Copenhagen/1103 and Lille Valby/2090 in 2009.

# 12 Ozone precursors

Measurements of selected ozone precursors were initiated in 2009 on H.C. Ørsteds Institute, Copenhagen/1259, and at Lille Valby/2090 in Roskilde approximately 30 km west of Copenhagen. Ambient air was sampled on adsorbent tubes and analysed by thermal desorption gas chromatography mass spectrometry. The major ozone precursors are toluene and benzene on both stations. Anthropogenic compounds are generally more abundant in the urban background air. Isoprene, which has biogenic sources that exceed the anthropogenic ones on a yearly basis, peaks in the summer and is low during the winter months. Urban Isoprene can exceed rural isoprene in the winter due to the traffic source.

## 12.1 Annual statistics

**Table 12.1.** Annual statistics based on daily averages for selected ozone precursors in semi-rural background measured on Lille Valby/2090.

| Unit ug/m$^3$ | observations | average | 90% percentile |
|---|---|---|---|
| benzene | 209 | 0.79 | 1.75 |
| toluene | 210 | 0.70 | 1.59 |
| ethylbenzene | 210 | 0.12 | 0.25 |
| m,p-xylene | 209 | 0.14 | 0.32 |
| o-xylene | 209 | 0.11 | 0.27 |
| 1,3,5-TMB | 169 | 0.021 | 0.053 |
| 1,2,4-TMB | 167 | 0.089 | 0.20 |
| 1,2,3-TMB | 148 | 0.025 | 0.061 |
| isoprene | 121 | 0.11 | 0.27 |
| 1-pentene | 113 | 0.087 | 0.21 |
| trans-2-pentene | 133 | 0.014 | 0.023 |
| n-pentane | 179 | 0.41 | 0.78 |
| hexane | 200 | 0.15 | 0.31 |
| n-heptane | 168 | 0.045 | 0.094 |
| n-octane | 111 | 0.049 | 0.10 |
| isooctane | 156 | 0.044 | 0.085 |
| 2-methylpentane | 199 | 0.28 | 0.53 |

**Table 12.2.** Annual statistics based on daily averages for selected ozone precursors in urban background measured on H.C. Ørsteds Institute, Copenhagen/1259.

| Unit ug/m$^3$ | observations | average | 90% percentile |
|---|---|---|---|
| benzene | 233 | 0.78 | 1.74 |
| toluene | 235 | 1.51 | 2.51 |
| ethylbenzene | 235 | 0.20 | 0.37 |
| m,p-xylene | 235 | 0.28 | 0.54 |
| o-xylene | 234 | 0.26 | 0.45 |
| 1,3,5-TMB | 130 | 0.051 | 0.10 |
| 1,2,4-TMB | 129 | 0.20 | 0.34 |
| 1,2,3-TMB | 128 | 0.058 | 0.091 |
| isoprene | 147 | 0.064 | 0.13 |
| 1-pentene | 136 | 0.093 | 0.19 |
| trans-2-pentene | 167 | 0.035 | 0.069 |
| n-pentane | 204 | 0.83 | 1.37 |
| hexane | 226 | 0.23 | 0.41 |
| n-heptane | 232 | 0.37 | 0.48 |
| n-octane | 169 | 0.087 | 0.15 |
| isooctane | 196 | 0.16 | 0.26 |

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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 (Harrison, 2006).
- 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 part of the particle mass prior to determination of $PM_{10}$. Diurnal averages of TEOM-$PM_{10}$ are 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 ($R^2 = 0.90$).

When reporting data 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 if no local correction factor has been determined. 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 is concluded that the NERI estimate gives results in good agreement with the measurements using SM200 or 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 a simple estimate using a factor of 1.3.

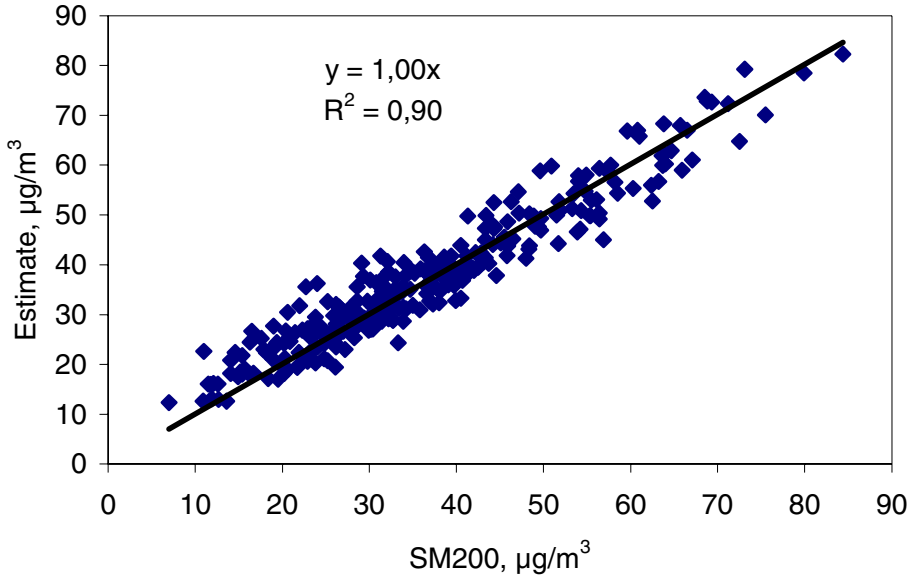


**Figure 1.** Comparison of the direct measurements of PM10 using SM200 and the NERI estimate of PM10 for the period 2006 to 2008 at HCAB. The NERI estimate is determined on basis of measurements of PM10 using TEOM at HCAB and HCØ in addition to measurements of PM10 using SM200 at HCØ. Data from 278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

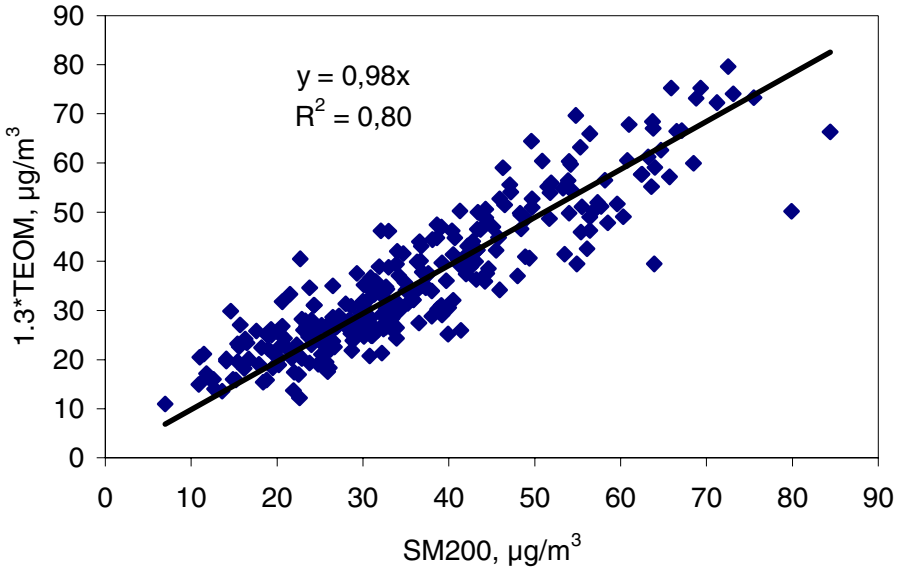


**Figure 2**. Comparison of the direct measurements of $PM_{10}$ using SM200 and the simple estimate of $PM_{10}$ for the period 2006 to 2008 at HCAB. The simple estimate is calculated by multiplication of TEOM-$PM_{10}$ with a factor of 1.3. Data from 278 days. The regression line is a simple linear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

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# THE DANISH AIR QUALITY MONITORING PROGRAMME

Annual Summary for 2009

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 understand the governing processes that determine the level of air pollution in Denmark. In 2009 the air quality was measured in four Danish cities and at two background sites. In addition model calculations were carried out to supplement the measurements. At the two street stations in Copenhagen $NO_2$ were found in concentrations above EU limit values plus margin of tolerance. In the previous years $PM_{10}$ was above the limit value. However, in 2009 $PM_{10}$ has decreased at H.C.Andersens Boulevard and no exceedance of the limit value was observed. The concentrations for most pollutants have been strongly decreasing during the last decades, however, only a slight decrease has been observed for $NO_2$ and $O_3$.

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