THE DANISH AIR QUALITY MONITORING PROGRAMME

Annual Summary for 2010

NERI Technical Report no. 836 2011

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

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Abstract: The air quality in Danish cities has been monitored continuously since 1982 within the Danish Air Quality Monitoring 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 2010 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 only one street station (H.C. Andersens Boulevard) in Copenhagen NO_2 was found in concentrations above EU limit values while NO_2 in Odense, Aarhus and Aalborg was below the limit value. Model calculations indicate exceedances of NO_2 limit values at several streets in Copenhagen. Both PM_{10} and $PM_{2.5}$ were below limit values at all stations. 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.

Keywords: Atmospheric pollution, urban pollution, nitrogen compounds, ozone, sulphur compounds, heavy metals, volatile organic pollutants, dispersion models

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Summary and Conclusion

This report presents the result of the Danish Air Quality Monitoring Programme in 2010. 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), nitrogen oxides (NO_x/NO_2), particulate mass (PM_{10} and $PM_{2.5}$), particle number, benzene (C_6H_6), 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 as well as to follow trends. Further, the program serves as basis for determination of sources of the air pollutants, basis for evaluation of the impact of regulations of emissions and as basis for various research projects related to air quality.

Due to the revision of the monitoring program there is a number of changes in the monitoring program and in this years report. The main changes are the following:

- The two Danish monitoring programs (the Background monitoring programme aimed at assessing the atmospheric depositions to nature and the Air quality monitoring program measurements related to human health) has been integrated into one program with two annual reports. The first one with focus on air quality and human health and the second one with focus on air quality and environment. The material previously presented in this report on air quality and vegetation has therefore been moved to the second report.
- The rural monitoring station at Lille Valby was moved about two km west in June 2010 and is now situated at Risø close to NERI.
- Activities concerning measurements of heavy metals have been reduced because the concentrations are low compared to limit values. Moreover, a new analysis technique has been used for analysis of heavy metals. It has therefore only been possible to analyse for those five heavy metals that are included in the EU directives. However, it is expected that more metals will be included during 2011.
- As a new thing this report presents results from analysis of sodium. This is in order to be able to correct PM_{10} for the content of salt from sea and winter salting of roads.
- Finally, the report presents results from measurements of number of particles in Copenhagen.

PM_{10} were at all the stations below both the annual limit value (40 µg/m^3) and the limit value for the 35th highest daily average value for PM_{10} (50 µg/m^3). $PM_{2.5}$ was lower than the annual limit value (25 µg/m^3) valid from 2015. The number of particles in ambient air were about 16000 particles per cm^3 at the street station H.C. Andersens Boulevard. This is considerably higher than in urban and rural background. A significant reduction in particle number has been observed since 2002.

The sodium content in PM_{10} on street stations were about 1 µg/m^3 corresponding to en estimated annual salt content (NaCl) of about 2.6 µg/m^3. High diurnal values of salt above 10 µg/m^3 was observed during periods with salting of roads.

The annual limit value for NO_2 (40 µg/m^3 in 2010) was exceeded at one street station in Copenhagen (H.C. Andersens Boulevard), whereas no exceedances were observed in Odense, Aalborg and Aarhus. The NO_2 concentrations generally decreased in 2010. However, at one station in Copenhagen (1103) an increase was observed. This is believed to be a temporary effect due to ongoing local construction work at two nearby sites.

Model calculations at selected streets in Copenhagen and Aalborg indicate that the limit value was exceeded at several streets in Copenhagen but not in Aalborg in 2010. In general modelling confirmed that the street station at H.C. Andersens Boulevard (1103) in Copenhagen represents one of the most polluted streets in Copenhagen, whereas the traffic station in Aalborg (6153) represents the average level for the 31 selected streets in Aalborg. Due to new traffic information Sydhavnsgade in Copenhagen has now significant higher NO_2 concentration as now by far the most polluted street of the 138 selected streets in Copenhagen. The model calculations show a tendency for high concentrations on streets with housing on one side of the street and open space on the other side. NERI will in 2011 participate in a project with Danish EPA with supplementary measurements in order to examine some of the hot spot situations in Copenhagen further.

The ozone levels were in 2010 almost the same as in 2009 at all rural and urban background stations and no clear trend was thus observed. The information threshold at 180 µg/m^3 was exceeded once. The target value for the max 8 hours ozone concentration on 120 µg/m^3 was not exceeded, but the long-term objective for this target was exceeded at all non-traffic stations.

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 south of Denmark.

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 0.34 ng/m^3. The target value for benzo[a] pyrene (1 ng/m^3) was not exceeded in 2010.

Actual data, 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 2010 fra Overvågningsprogrammet for luftkvalitet i danske byer. Programmet, som udføres af Danmarks Miljøundersøgelser (DMU) ved Aarhus Universitet, er baseret på målinger ved ni målestationer placeret i de fire største danske byer samt 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 og øvrige danske behov måles koncentrationer af svovldioxid (SO_2), nitrogenoxider (NO_x/NO_2), partikelmasse (PM_{10} og $PM_{2.5}$), partikel antal, benzen (C_6H_6) og toluen (C_7H_8), carbonmonoxid (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. Målingerne og modelberegningerne anvendes til at vurdere om EU's grænseværdier for luftkvalitet er overholdt. Rapporten beskriver endvidere udviklingen i koncentrationerne. Desuden tjener resultaterne som grundlag for vurdering af kilderne til luftforureningen, vurdering af effekt af reduktionstiltag 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 indført en grænseværdi for $PM_{2.5}$, som skal overholdes i 2015.

Overvågningsprogrammet er blevet revideret i 2010 og som følge heraf er der foretaget en række ændringer i programmet og i dette års rapport. De væsentligste ændringer er følgende:

- De to danske luftovervågningsprogrammer (Baggrundsovervågningsprogrammet med fokus på den atmosfæriske afsætning på natur og vandmiljø samt Luftkvalitetsmoniteringsprogrammet med fokus på sundhed) er blevet lagt sammen til et samlet overvågningsprogram med to årlige rapporter. Den første rapport har fokus på luftkvalitet i relation til sundhed og den anden har fokus på luftkvalitet og miljø. Materiale i relation til luftkvalitet og miljø er derfor flyttet fra den første rapport over til den anden rapport.
- Landbaggrundsmålestationen ved Lille Valby er blevet flyttet ca. 2 km mod vest i juni 2010 og er nu placeret på Risø tæt ved DMU-AU.

- Målinger af tungmetaller er blevet reduceret i det reviderede program, fordi koncentrationerne er lave i sammenligning med grænseværdierne. Endvidere er der taget en ny analyseteknik i brug ved analyserne for tungmetaller, hvilket har medført at der kun er analyseret for de fire tungmetaller, som er omfattet af direktiverne. Det forventes at antallet af tungmetaller vil blive udvidet i 2011.
- Som en ny ting præsenterer rapporten resultater fra analyse af indholdet af natrium i PM_{10}, således at det vil være muligt at korrigere PM_{10} for indholdet af hav- og vejsalt.
- Endelig præsenterer rapporten for første gang resultater fra måling af antallet af luftbårne partikeler i København.

De væsentligste konklusioner fra overvågningsprogrammet i 2010 er følgende:

- I 2010 blev grænseværdien for NO_2 overskredet på en (H.C. Andersens Boulevard) af de to gademålestationer i København. I Odense, Aarhus og Aalborg var der ingen overskridelser. Koncentrationerne af NO_2 faldt generelt fra 2009 til 2010, undtagen på gademålestationen ved H.C. Andersens Boulevard (1103) i København, hvor en stigning blev observeret. Stigningen skyldes formentligt en midlertidig påvirkning fra to større byggerier nær ved målestationen.
- Modelberegninger indikerer, at grænseværdien i 2010 var overskredet på en række gadestrækninger i København, men ikke på udvalgte gadestrækninger i Aalborg. Modelberegningerne viste endvidere, at gademålestationen ved H.C. Andersens Boulevard (1103) i København repræsenterer en af de mest forurenede gader i København, mens gademålestationen i Aalborg (6153) repræsenterer et middelniveau set i forhold til de 31 udvalgte gader i Aalborg. Sydhavnsgade i København har nu en betydeligt højere koncentration af NO_2 end tidligere rapporteret og er nu den gade med de højeste koncentrationer. Årsagen til dette skift er nye trafikinformationer fra Københavns Kommune. Modelberegningerne viser en tendens til, at gader med de højeste koncentrationer af NO_2 er gader med såkaldt ensidig bebyggelse – dvs. høje huse på den ene side og ingen bebyggelse på den anden side. DMU vil i 2011 deltage i et projekt sammen med Miljøstyrelsen med supplerende målinger af NO_2 med det formål at undersøge situationer med meget høje NO_2-koncentrationer yderligere.
- I 2010 var der ingen målestationer, hvor grænseværdierne for luftens indhold af partikler mindre end 10 µm (PM_{10}) blev overskredet.
- Indholdet af partikler mindre end 2.5 µm ($PM_{2.5}$) overskred ikke de kommende grænseværdier, som skal overholdes fra 2015.
- Antallet af partikler mellem 6 og 700 nm var omkring 16.000 partikler per cm^3 på gademålestationen H.C. Andersens Boulevard, mens det var betydeligt mindre i by- og landbaggrund. Antallet af partikler er faldet betydeligt siden 2002.
- Indholdet af natrium i PM_{10} på gademålestationerne var omkring 1 $µg/m^3$ svarende til et estimeret saltinhold (NaCl) på omkring 2.6 $µg/m^3$. Høje døgnmiddelværdier på over 10 $µg/m^3$ blev observeret i perioder med saltning af veje.

- Der er ikke fastsat egentlige grænseværdier for ozon (O_3), men kun "målværdier" og "langsigtede mål" (hensigtsværdier). Der var i 2010 ingen overskridelser af målværdierne for beskyttelse af sundhed. mens de langsigtede mål blev overskredet på alle bybaggrunds- og landstationerne. Tærsklen for information af befolkningen om høje ozonniveauer (timemiddel 180 µg/m^3) blev overskredet én gang i løbet af sommeren 2010.
- 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 0,34 ng/m^3. Målværdien på 1 ng/m^3 var således ikke overskredet i 2010.
- For andet år 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 background 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 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 operating and maintaining the 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. In addition, this report presents results from model calculations of air quality in Denmark carried out as supplement to the measurements.

The monitoring 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) 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 had to be attained in 2005 or here from 2010.

The program was revised in 2010. Due to this revision of the monitoring program there is a number of changes in the monitoring program and in this years report. The main changes are the following:

- The two Danish monitoring programs (the background monitoring programme aimed at assessing the atmospheric depositions to nature and the air quality programme measurements related to human health) has been integrated into one program with two annual reports. The first one with focus on air quality and human health and the second one with focus on air quality and environment. The material previously presented in this report on air quality and vegetation has therefore been moved to the second report.

- The rural monitoring station at Lille Valby was moved about two km west in June 2010 and is now situated at Risø close to NERI.
- The program concerning measurements of heavy metals has been reduced since the concentrations are low compared to limit values. Moreover, a new analysis technique has been used for analysis of heavy metals. This limits the amount of metals that could be analysed. However, it is expected that more metals will be included during the next 2011.
- As a new thing this report presents results from analysis of sodium. This is in order to be able to correct PM_{10} for the content of salt from sea and winter salting of roads.
- Finally, the report presents results from measurements of number of particles in Copenhagen.

In the following chapters the results from measurements and model calculations for 2010 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

2.1 Measurements

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. The rural station at Lille Valby was in the middle of 2010 moved about 2 km west to Risø and is now situated close to the National Environmental Research Institute. Further information about the program and results is found at the website: http://www.dmu.dk/International/Air.

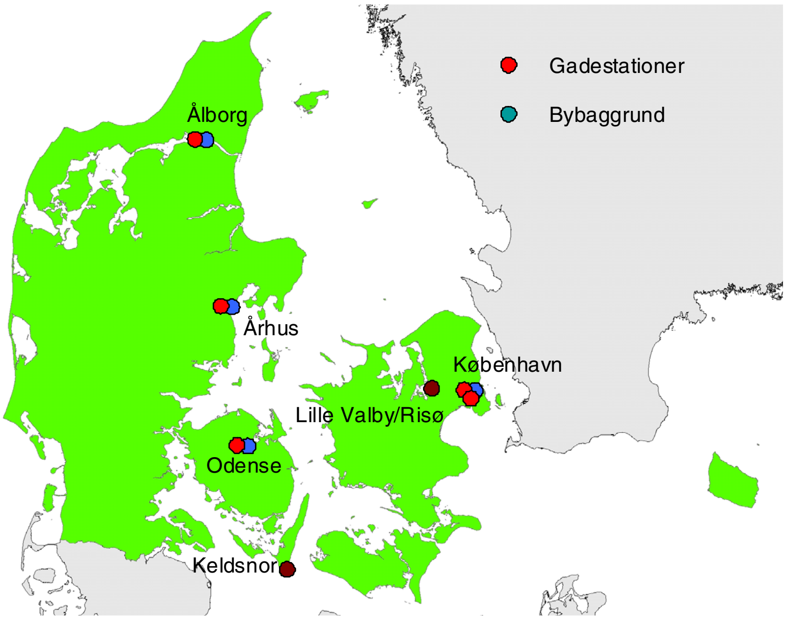


Figure 2.1 Main stations used for monitoring of air quality in relation health.

Table 2.1. Main stations used for monitoring of air quality in relation to health in 2010

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/Risø	-	Rural
Keldsnor/9055	-	Rural

The following compounds were measured in 2010:

- Nitrogen oxides (nitrogen monoxid (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/Risø.
- 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/Risø by means of TEOM. Part of these measurements was carried out in a research project funded separately by the Danish EPA.
- Particle number were measured at Copenhagen/1103, Copenhagen/1259 and Lille Valby/Risø in cooperation with particle research funded separately by the Danish EPA.
- Ozone (O_3) was measured at all urban background and rural stations, and at the street stations Copenhagen/1257 and Copenhagen/1103
- Carbon monoxide (CO) was measured at all street stations as well as at the urban background station, Copenhagen/1259 and the rural site Lille Valby /Risø.
- 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.
- Elemental carbon (EC) and organic carbon (OC) were measured at Copenhagen/1103 and Lille Valby/Risø.
- 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) and particle number 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. EC and OC 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. The actually applied measurement methods are listed at the website: http://www.dmu.dk/En/Air.

2.2 Model calculations

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 to urban background scale and further down to individual street canyons in cities – on both sides of the streets (thor.dmu.dk). At present, the system includes global meteorological analyzed data from National Centres for Environmental Prediction, United States, which is used as input to 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 (Christensen, 1997; Brandt et al., 2011), 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 integrated THOR 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, atmospheric transport, chemical reactions, and dry- and wet depositions of air pollutants are calculated in a 3D grid covering the northern hemisphere with a resolution of 150 km x 150 km. The model includes a two-way nesting capability, which makes it possible to obtain higher resolution over limited areas. Three nested domains are used in LMP, where the first nest is covering Europe with a resolution of 50 km x 50 km. The second nest is covering Northern Europe with a resolution of 16.7 km x 16.7 km. The calculations of air quality in Denmark are carried out in a third nest with a horizontal resolution of 5.6 km x 5.6 km. In the vertical direction the model is divided into 29 layers covering the lowest 15 km of the atmosphere. Of these the lowest layers are relatively thin (20 m) while the upper layers are relatively thick (2000 m). The model includes a comprehensive chemical scheme designed for calculation of the chemical reactions in the lower part of the atmosphere. The model calculations for 2010 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 of 1 km x 1 km for Denmark transformed into the 5.5 km x 5.5 km resolution domain 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 sources are areal sources like 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). The emissions used in the UBM model are based on the newly developed SPREAD model that spatially distributes national emissions from 2008 from all sectors on a 1 km x 1 km grid for Denmark (Plejdrup & Gyldenkærne 2011). Previous assessments have only included road traffic emissions also on a 1 km x 1 km grid for Denmark but using a bottom up approach based on traffic levels on the road network and emission factors from the emission module of the OSPM model.

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 MM5v3 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 turbulence induced by traffic).

The traffic emission data used as input for the calculations with OSPM have been substantially updated for this year's report by detailed information (average daily traffic, vehicle distribution) for the selected streets obtained from the municipalities of Copenhagen and Aalborg based on a project on evaluation of the effects of environmental zones (Jensen at al. 2011). Emission factors are based on the latest version of the COPERT IV model applied for 2010 conditions taking account of the effect of the environmental zones by means of a detailed analysis of the vehicle composition using video number plate analysis linked to the National Auto Registry at a street in Copenhagen, for details see Jensen at al. (2011). 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 2010 for Copenhagen and Aalborg have been carried out using the full model calculation system based on the THOR system, including DEHM, UBM, and OSPM. The calculations were carried out in order to determine the NO_2 concentration in 138 streets in Copenhagen and 31 streets in Aalborg.

3 Nitrogen oxides

3.1 Yearly statistics

Table 3.1. Nitrogen dioxide (NO_2) in 2010. All parameters are based on hourly averages.

Unit: µg/m^3	Number	Average	Median	98. percentile	19. highest
Traffic:					
Copenhagen/1257	8028	39	35	97	130
Copenhagen/1103	7405	56*)	51	129	181
Aarhus/6153	8310	39	35	97	135
Odense/9155	7836	32	25	90	125
Aalborg/8151	7955	39	30	116	148
Urban Background:					
Copenhagen/1259	7918	17	14	53	71
Aarhus/6159	8237	21	17	64	93
Odense/9159	8116	18	14	58	86
Aalborg/8158	7869	16	11	57	83
Rural:					
Lille Valby/Risø	7078	11	7	41	67
Keldsnor/9055	8123	8	5	32	56
Limit valuem2010	>7455	40			200

*) Limit value exceeded.

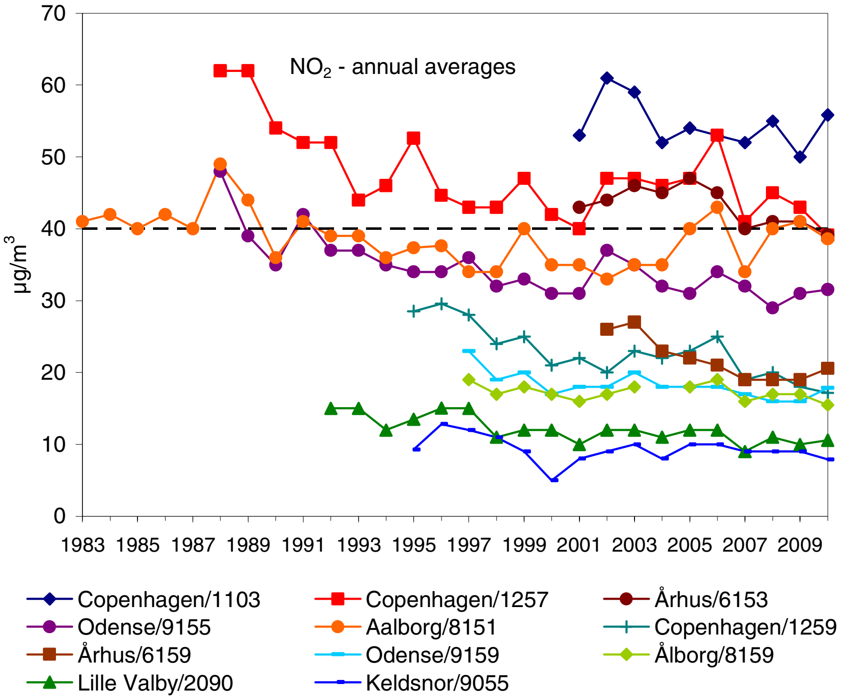
Table 3.2. Nitrogen oxides (NO_x=NO+NO_2) 2010. All parameters are based on hourly averages.

Unit: µg/m^3 (as NO_2)	Number	Average	Median	98. percentile	19. highest
Traffic:					
Copenhagen/1257	8028	86	66	287	479
Copenhagen/1103	7405	133	105	416	679
Aarhus/6153	8310	87	67	308	696
Odense/9155	7836	75	43	340	616
Aalborg/8151	7955	104	68	416	587
Urban Background:					
Copenhagen/1259	7918	21	16	74	144
Aarhus/6159	8237	34	20	169	472
Odense/9159	8116	24	17	92	282
Aalborg/8158	7869	23	14	109	295
Rural:					
Lille Valby/Risø	7078	12	8	52	105
Keldsnor/9055	8123	9	6	36	67

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

Number of informations to the public due to exceedance of the alert threshold for NO_2 (three hours average 400 µg/m³) in 2010: 0.

3.2 Trends



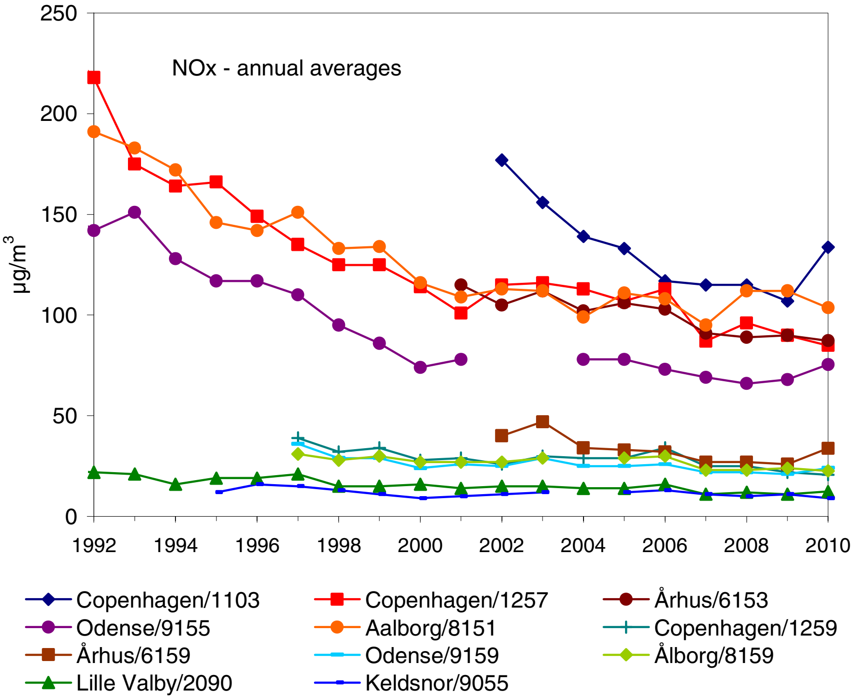


Figure 3.1 The graphs show the time series for the annual average values of NO_2 and NOx. The dashed line on the upper graph indicates the limit value that enters into force in 2010. Previous results from Copenhagen/1103 can be found at the homepage of Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk)

Both NO_2 and NO_x increased in 2010 compared to 2009 at the street station H.C. Andersens Boulevard (Copenhagen/1103). At all other stations the levels were as in 2009 or a slight decrease was observed. The increase observed at H. C. Andersens Boulevard is believed to be a temporary effect due to ongoing local construction work at two nearby sites.

3.3 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 31 in Aalborg. Average Daily Traffic (ADT) was between 9,200 and 67,000 vehicles/day in Copenhagen and between 2,700 and 29,000 vehicles/day in Aalborg. Based on information from Copenhagen and Aalborg municipalities the ADT and vehicle distribution on all streets have been updated compared to last year's report. This work was performed within a project on the evaluation of the effects of environmental zones, see details in Jensen et al. (2011). One street in Aalborg (Ved Stranden) was omitted from calculations on request from the Municipality of Aalborg since traffic in 2010 on this street is not representative for normal conditions due to ongoing construction affecting traffic at this street.

Model calculations have been carried out in order to determine the annual concentrations of NO_2 to be able to compare with limit values. The air quality limit value for the annual mean is 40 $\mu g/m^3$ in 2010. 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 especially for heavy duty vehicles, resulting in a higher number of weight classes for trucks and buses, now 19 classes in comparison to 6 classes before. The composition of the vehicle fleet has been updated according to the database used in the national emission reporting and detailed video number plate analysis performed on one street in Copenhagen and linked to information from the National Auto Registry. Therefore the vehicle composition takes account of the effect of the environmental zones introduced in Copenhagen and Aalborg (Jensen at al. 2011).

The environmental zones have been implemented in Denmark for five urban areas: the municipalities of Copenhagen, Frederiksberg, Aarhus, Odense and Aalborg. The environmental 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 environmental zones came into force in Copenhagen on September 1, 2008 and in Aalborg on February 1, 2009.

Although the environmental 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.

As part of a project, that evaluates the effects of the environmental zones on air quality in Denmark, the full effect of the environmental zones (stage two) has been evaluated for all 5 municipalities for 2010 (Jensen at al. 2011).

The calculations presented below for Copenhagen and Aalborg for 2010 include the full effect of the regulation (stage two) and are identical with the results presented in Jensen at al. (2011).

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 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 predicts annual NO_2 concentrations within ±20%.

3.3.1 Model calculations for Copenhagen

The annual mean concentrations of NO_2 for Copenhagen in 2010 are shown in Figure 3.2.

In 2010 the limit value for the annual mean concentration was exceeded in 29 out of the 138 selected streets in Copenhagen (Figure 3.3). In 2009 the number of streets exceeding the limit value plus margin of tolerance was 48. The average concentration at all streets has been reduced from 2009 to 2010 by about 4 µg/m^3. The reasons for the reduction between 2009 and 2010 are the reduction of the NO_x emissions due the introduction of the environmental zone and the normal renewal of the vehicle fleet with newer less polluting vehicles and the scrapping of older cars.

Moreover, the number of streets exceeding the limit value is very sensitive to small changes in concentrations and uncertainties in the assumptions taken in the emission estimation and model calculations as can be seen from Figure 3.2.

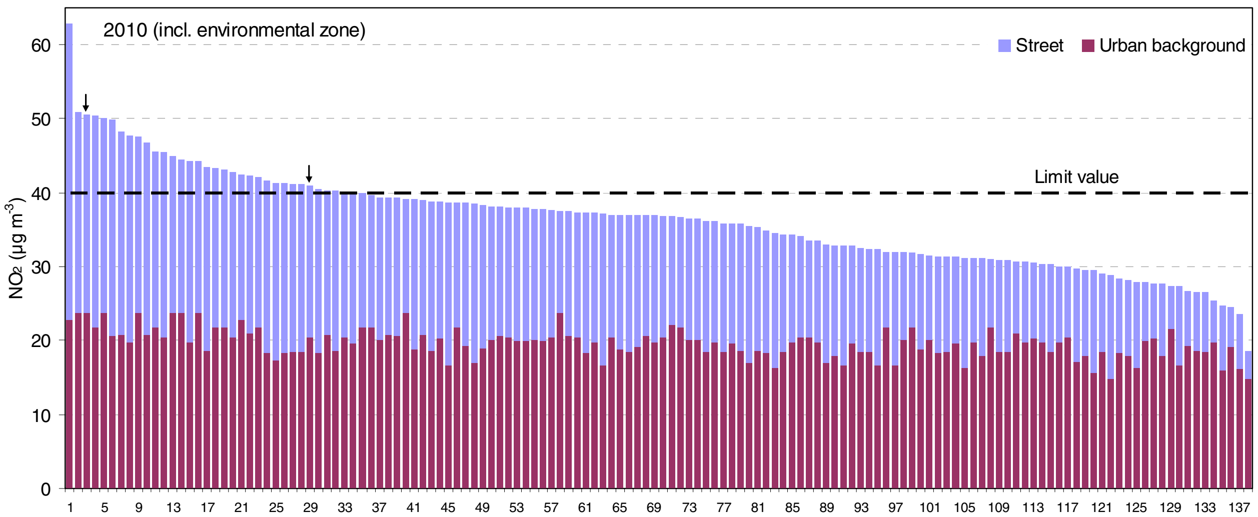


Figure 3.3 Annual mean concentrations of NO_2 in 2010 for 138 streets in Copenhagen. The contribution from traffic in the street canyons is based on the street canyon model OSPM. The urban background (dark red colour) is obtained from calculations with the urban background model UBM with input from the 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. Arrows indicate the street segments with measurement stations.

The streets where the limit value were exceeded all have a daily traffic intensity of more than about 12,000 vehicles per day. However, it is not only the traffic intensity alone 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 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 is not just concentrated to a few main roads but distributed throughout the city.

Due to the above mentioned major update of traffic information provided by the Copenhagen Municipality (Chapter 3.3) the order of the streets has been changed substantially compared to former years. The street Sydhavnsgade has replaced Nørre Søgade as the street with the highest NO_2 levels. Both streets are about 20 m wide and have buildings on only one side of about 18 m height. However, at Nørre Søgade the traffic input for the model calculations has been reduced by 11% to now 29 000 vehicles per day and the heavy-duty vehicles (HDV) has been reduced from about 8.3% to 2.9%. The fraction of HDV for Nørre Søgade was previously assumed to be similar to a standard urban street type (Type F) but is now based on an assessment of traffic counts. The traffic volume at Sydhavnsgade has been doubled to now 49 000 vehicles per day (4.7% HDV) and has most likely been underestimated in previous years. The Danish EPA has initiated a project scheduled for autumn 2011 that will measure NO_2 concentrations using passive samplers at some of the streets that show very high NO_2 levels in the model calculations. NERI participates in this project.

Table 3.5. Number and names for the streets that are shown in Figure 3.3 and 3.5. The streets are numbered (1-138) according to NO_2 levels in 2010 (1 = highest, 138 = lowest). The numbers in parenthesis refer to different segments of the same street that has more than one model calculation. * indicate the street segments with measurement stations.

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

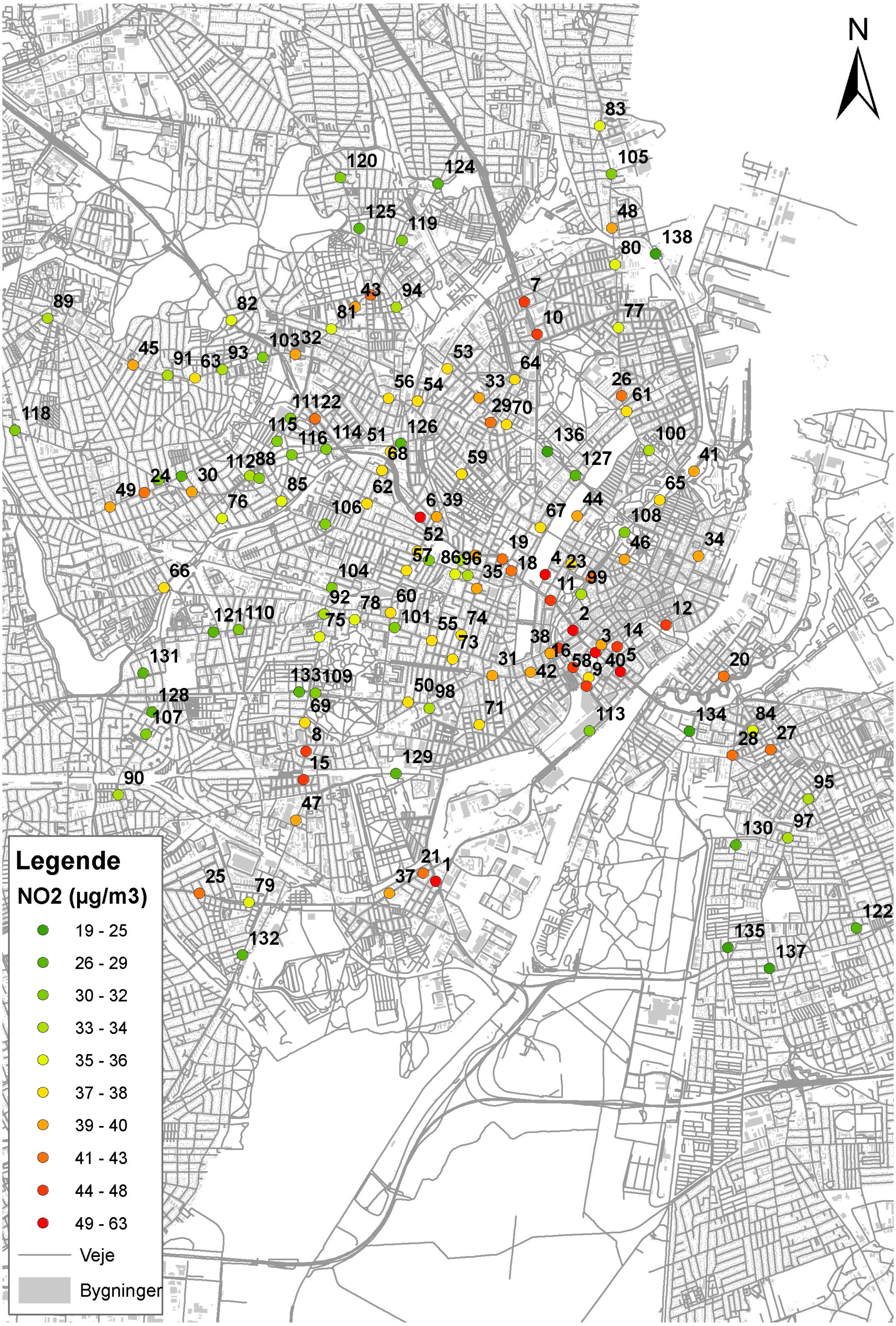


Figure 3.4 Map showing the locations of the selected streets in Copenhagen and the annual mean concentrations of NO_2 for 2010. The contribution from traffic in the street canyons is based on the street canyon model OSPM. The urban background is obtained from calculations with the urban background model 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.

3.3.2 Model calculations for Aalborg

For Aalborg the model calculations show in general a reduction in the NO_2 concentrations compared with 2009 for the same reasons given for Copenhagen in the previous section. The average NO_2 concentration was about 4 µg/m³ lower in 2010 than in 2009.

According to the model calculations the limit value for the annual mean concentration in 2010 was not exceeded at any of the 31 selected streets compared to 4 exceedances in 2009 (Figure 3.5 and Figure 3.6).

One street in Aalborg (Ved Stranden) was removed from the calculation streets on request from the Municipality of Aalborg since traffic on this street is not representative for normal conditions due to construction affecting traffic at this street.

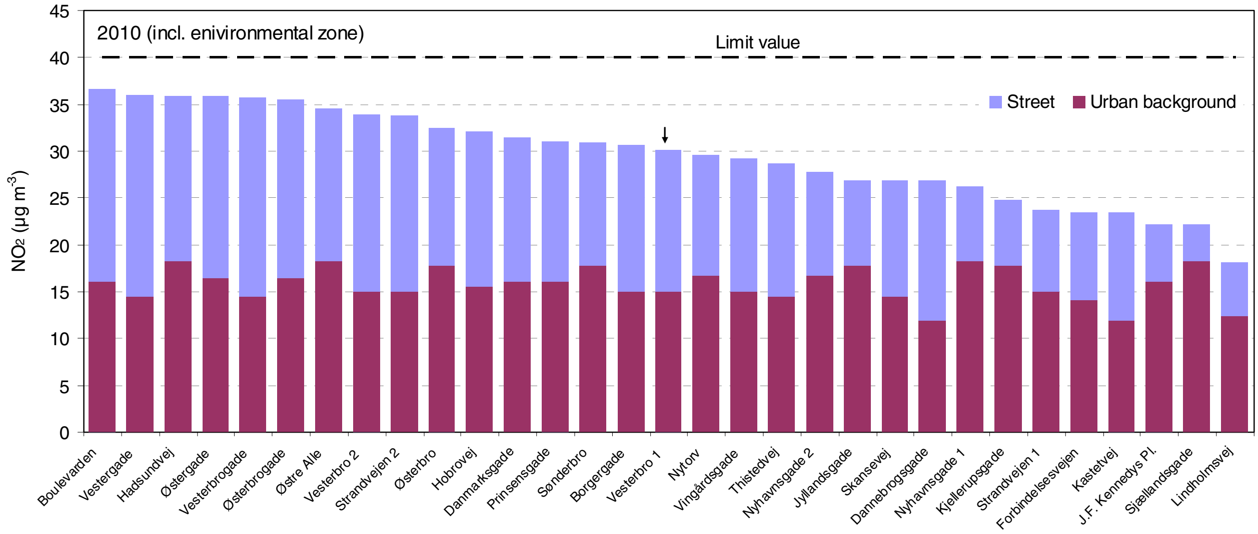


Figure 3.5. Annual mean concentrations of NO_2 in 2010 for 31 streets in Aalborg. The contribution from traffic in the street canyons is based on the street canyon model OSPM. The urban background (dark red colour) is obtained from calculations with the urban background model UBM with input from the regional scale model DEHM. The value for a street is for the kerb side with the highest annual mean concentration. Arrow indicate street segment with measurement station.

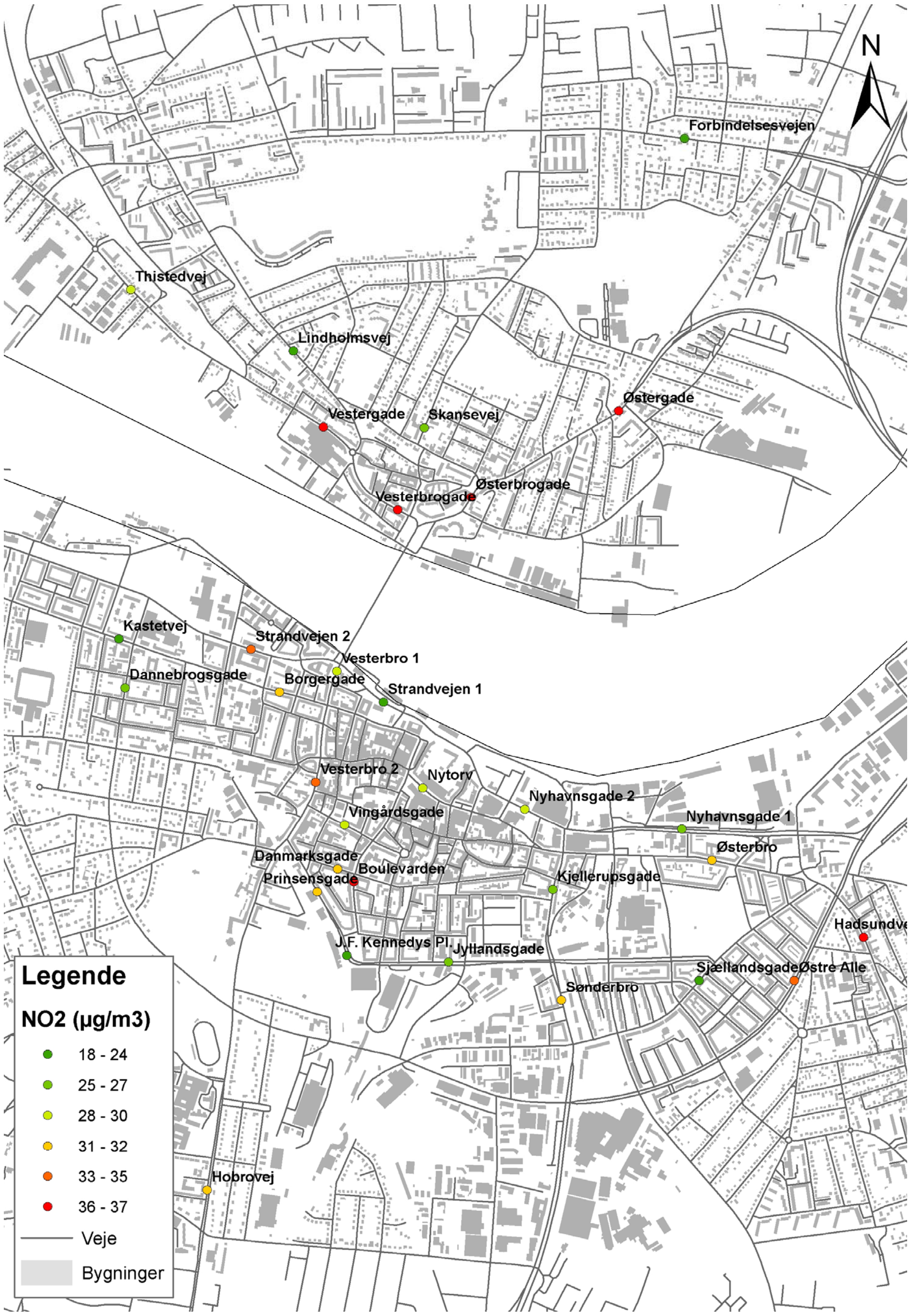


Figure 3.6. Map showing the location of the selected streets in Aalborg and the annual mean concentrations of NO_2 for 2010. The contribution from traffic in the street canyons is based on the street canyon model OSPM. The urban background is obtained from calculations with the urban background model 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. Vesterbro 1 is the street segment with the measurement station.

4 Ozone

4.1 Annual statistics

Table 4.1. *Ozone* (O_3) 2010. All parameters are based on one-hour average values. The eight hour values are calculated as a moving average based on hourly measurements. Days above target value is the number of days that the maximum running eight hour average exceeds 120 µg/m^3.

Unit: µg/m^3	Number of results	Average	Median	Max. 8 hours	Days above target value 8 hours	Max. 1 hour
Urban Background:						
Copenhagen/1259	7790	56	57	148	5	173
Århus/6159	8105	50	52	140	2	151
Odense/9159	7769	49	50	123	1	164
Aalborg/8158	7588	54	56	137	2	154
Rural						
Lille Valby/2090-Risø [1]	7494	57	60	120	0	129
Keldsnor/9055	7851	60	61	147	6	171
Traffic						
Copenhagen/1257	7594	40	39	116	0	136
Copenhagen/1103	7038	33	31	105	2	127
Target value	>7154	-	-	-	25	-
Long term objective	>7154	-	-	120	-	-

1. Lille Valby/Risø was closed down during part of the summer period due to the movement of the station

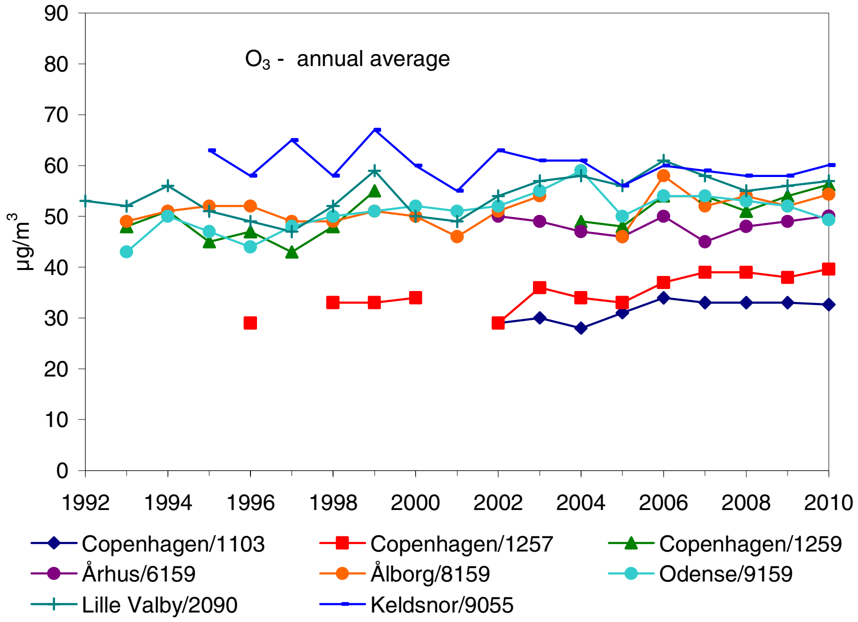
The maximum 8 hours daily mean value must not exceed 120 µg/m^3 more than 25 days per calendar year averaged over three years. This target value was not exceeded for 2008-2010 at any of the stations.

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 2010: 1 at the rural background station Ulborg.

Number of information to the public due to exceedance of the alert threshold (240 µg/m^3) in 2010: 0.

4.2 Trends



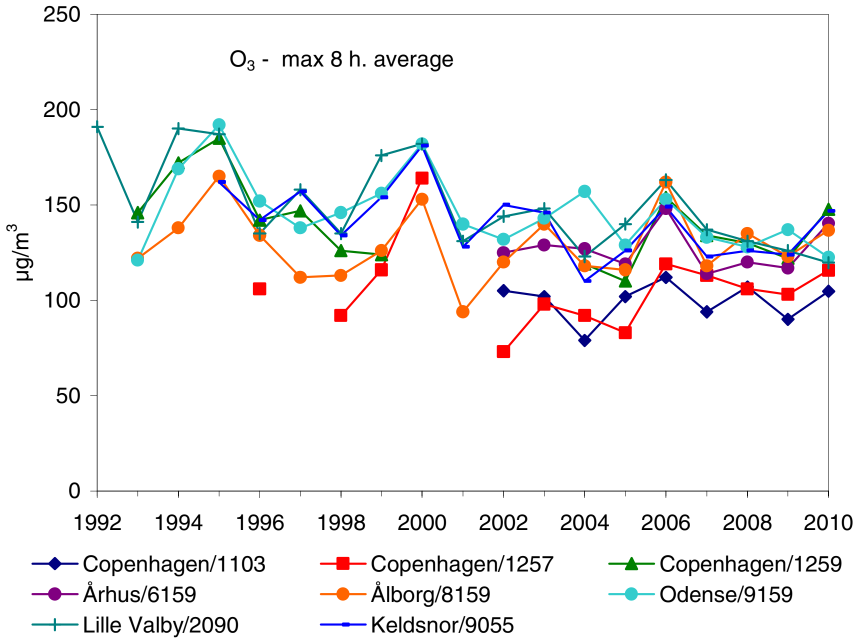


Figure 4.1 Annual average values and the max. 8 hour average value. The latter is calculated as hourly 8 hour running averages according to the provisions in the EU Directive (EC, 2008). Previous results from Copenhagen/1103 can be found at the Website of the Copenhagen Environmental Protection Agency (www. Miljoe.kk.dk).

4.3 Results from model calculations

The target value for protection of human health is that the running 8 hour means concentration of ozone must not exceed 120 µg/m³ 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/m³. The target value and long term objective are given in the EU Directive (EC, 2008). Results from the model calculations for 2010 show that the maximum daily 8 hour mean value was only exceeded 120 µg/m³ up 5 days during 2010 (Figure 4.3). Similar results were obtained for 2008 and 2009 and hence the target value was not exceeded. 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 average concentration exceeds the information threshold at 180 µg/m³. Based on measurements this threshold was exceeded one time in 2010 in western Jutland. The model calculations show that the one hour mean concentration did not exceed 180 µg/m³ in 2010 (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 2010.

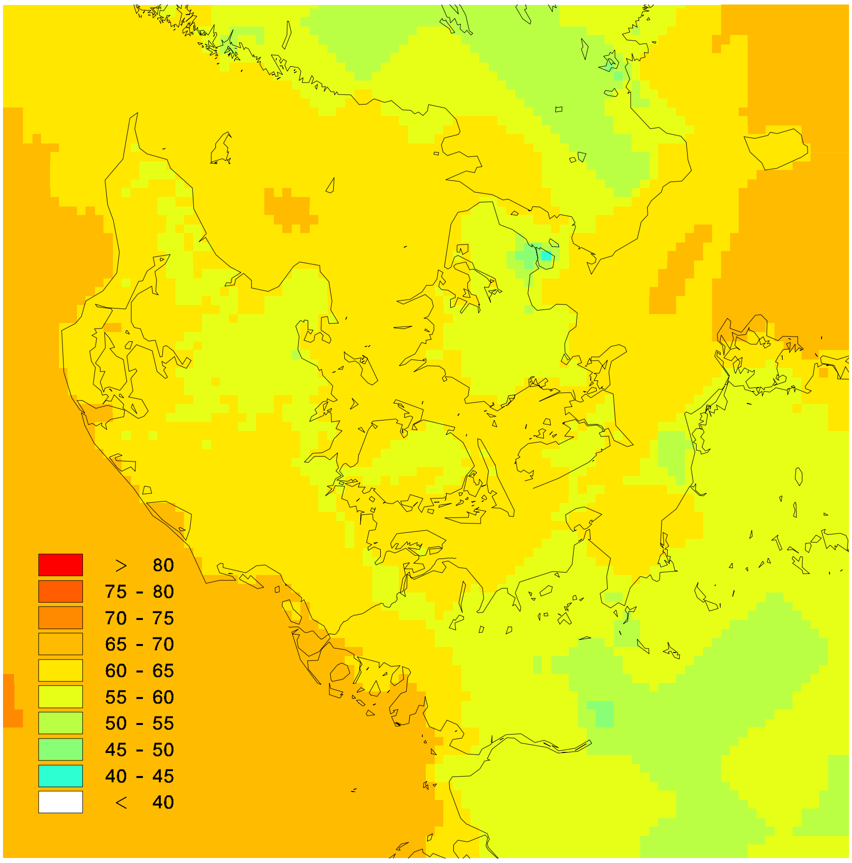


Figure 4.2. Annual mean concentrations of O_3 (µg/m3) for 2010 calculated using DEHM. The figure shows the average concentrations for the 6 km x 6 km grit cells used in the model.

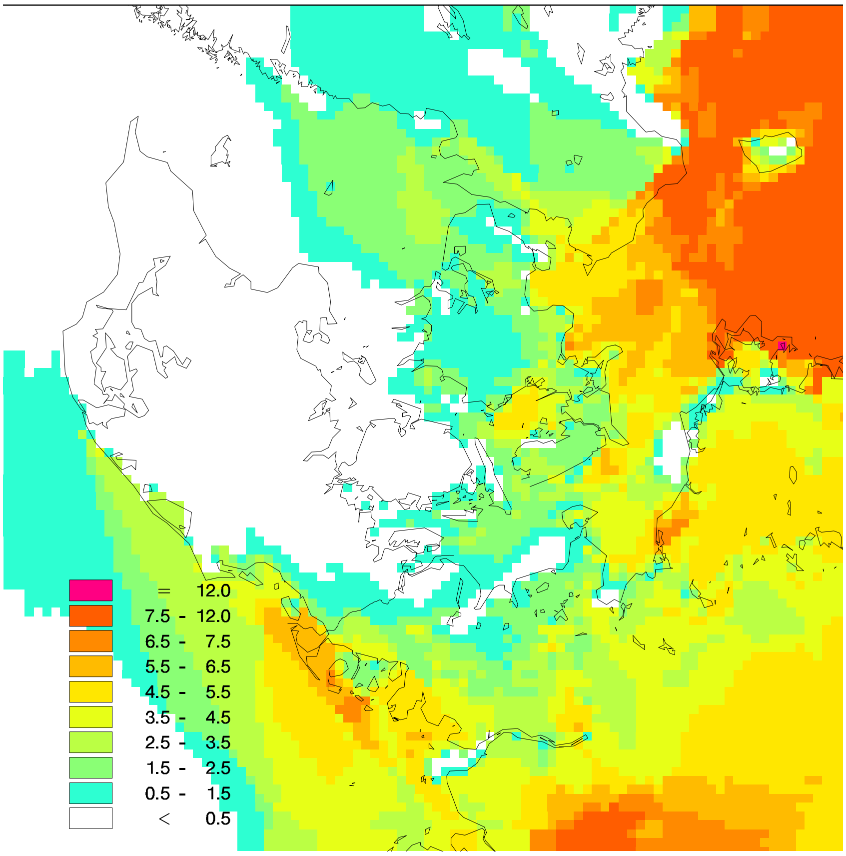


Figure 4.3. Number of exceedances of 120 μg/m^3 for 8-hour running mean concentrations of ozone in 2010. The calculations were carried out using DEHM.

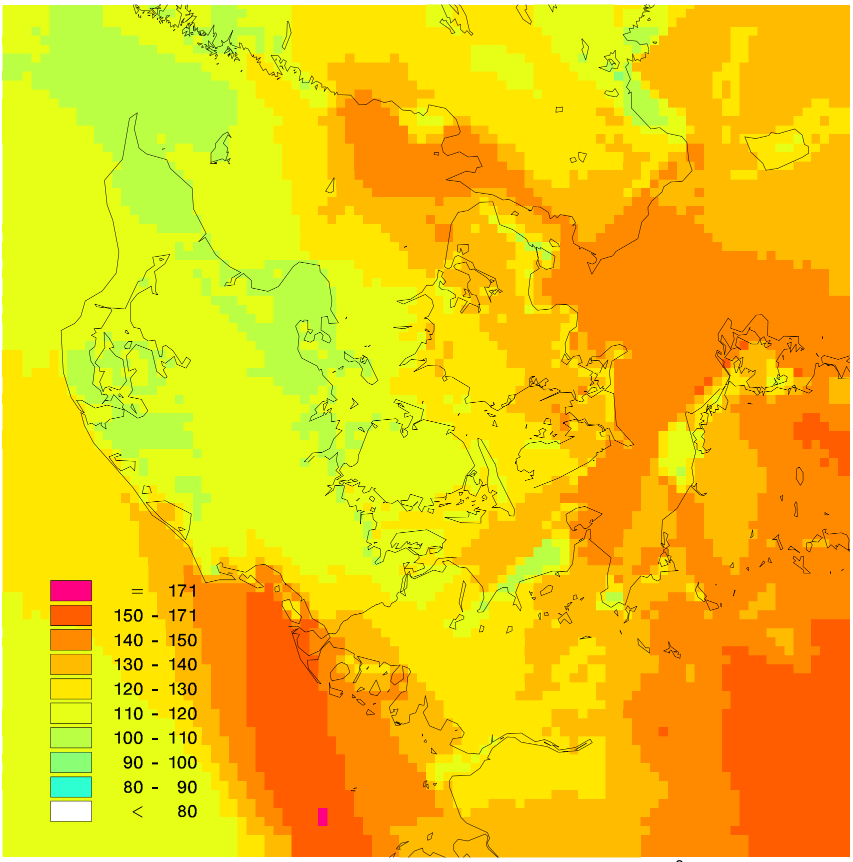


Figure 4.4. Maximum 8 hour running mean concentration (μg/m^3) of ozone in 2010 calculated using DEHM.

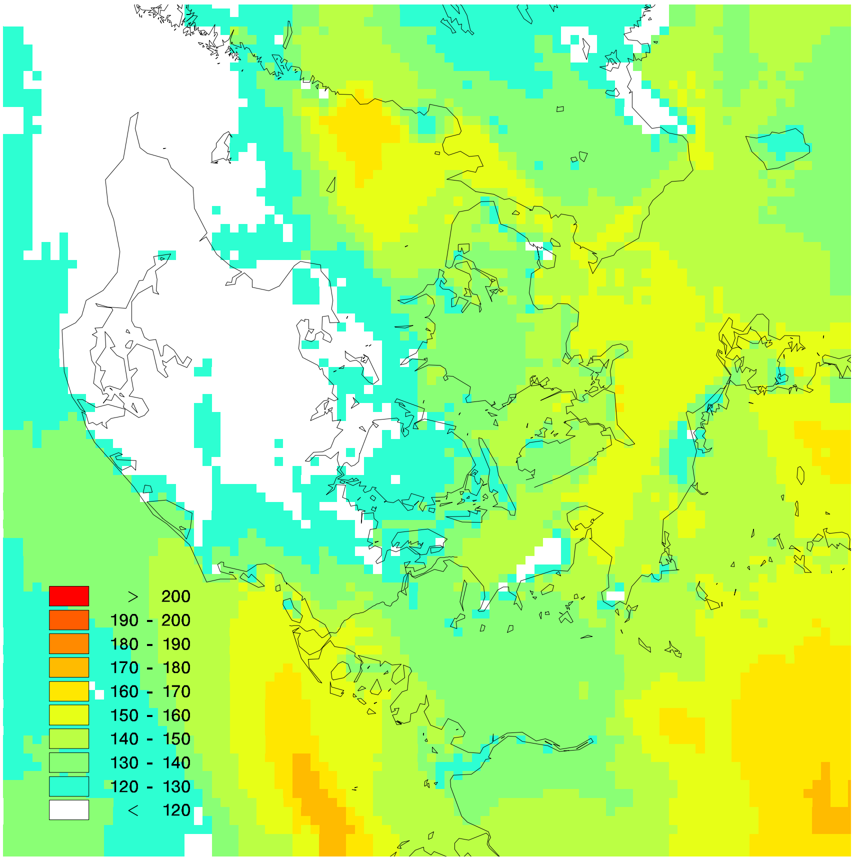


Figure 4.5. Maximum one hour mean concentration of ozone (µg/m3) in 2010 calculated using DEHM.

5 Carbon monoxide

5.1 Annual statistics

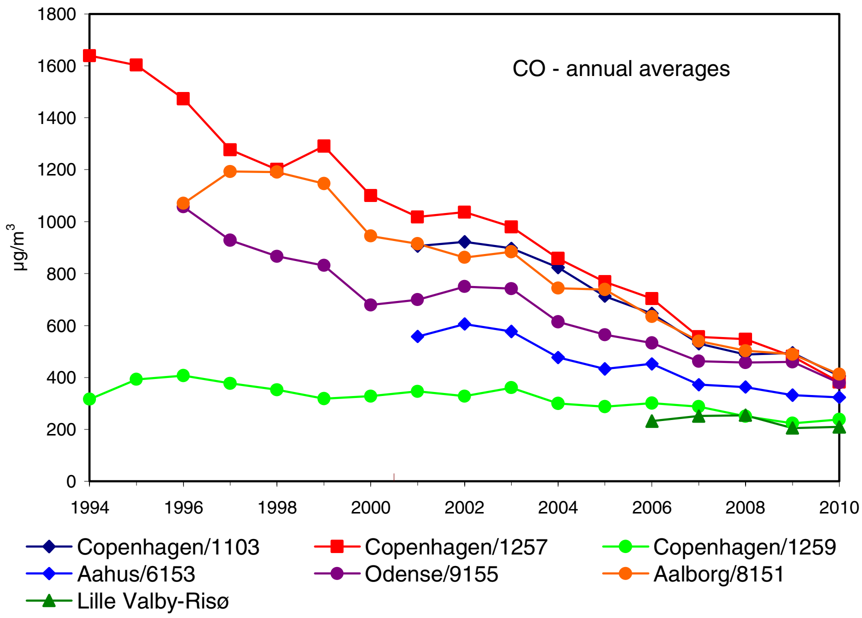
Table 5.1. Annual statistics for carbon monoxide (CO) in 2010. All parameters are based on hourly average. The 8-hour values are calculated as a moving average based on hourly results.

Unit: µg/m^3	**Number**	**Average**	**Median**	**98-percentile**	**99.9-percentile**	**Max. 8-hours**	**Max hour**
Traffic:							
Copenhagen/1257	7875	481	420	1242	1954	1642	2935
Copenhagen/1103	7596	510	463	1145	1638	1485	3194
Århus/6153	8066	406	356	966	1694	1843	2604
Odense/9155	7764	475	358	1535	2777	2576	4278
Aalborg/8151	7772	514	441	1275	1881	1515	2164
Urban Background:							
Copenhagen/1259	7782	297	279	594	977	919	1105
Rural							
Lille Valby/2090-Risø	7176	262	240	569	844	788	929
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



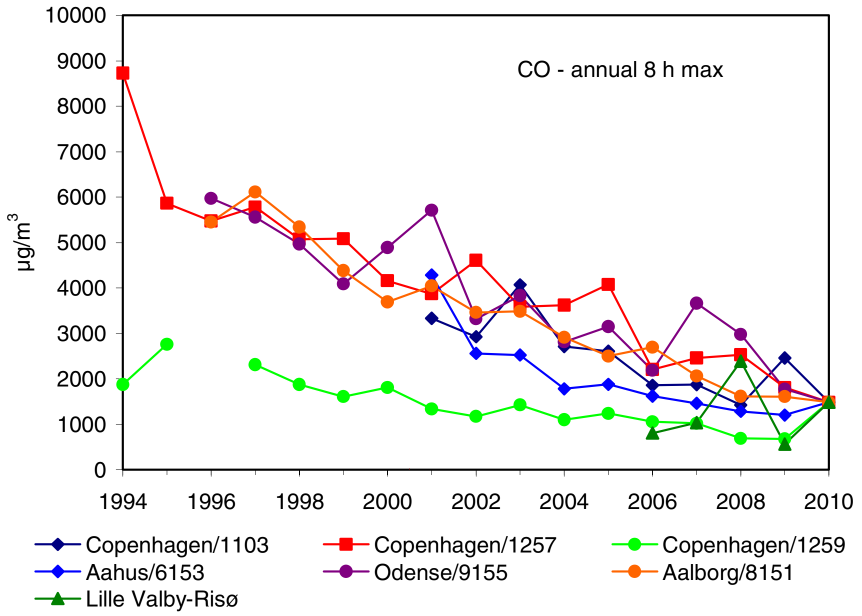


Figure 5.1. Annual average values and highest 8-hour value calculated based on an hourly moving average. Previous results from Copenhagen/1103 can be found at the website of the Copenhagen Environmental Protection Agency (www.Miljoe.kk.dk).

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. Moreover, benzene and toluene has been measured at urban background (H.C. Ørsteds Institute/1259) as part of the measurements of ozone precursors (Chapter 12).

6.1 Annual statistics

Table 6.1. Annual statistics for Benzene in 2010. The values are based on weekly averages.

Unit: µg/m^3	Number of results	Average	Max weekly average
Copenhagen/1103	50	1.3	3.0
Copenhagen/1257	48	1.4	3.5
Limit value		5	

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

Table 6.2. Annual statistics for Toluene in 2010. The Maximum weekly average is the maximum value for the weekly measurements (WHO, 2000).

Unit: µg/m^3	Number of results	Average	Max weekly average
Copenhagen/1103	50	3.4	6.0
Copenhagen/1257	48	3.7	6.4
Guideline value	-	-	260

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

The annual averages of benzene and toluene on H.C. Ørsteds Institute (1259) was measured to 0.75 µg/m^3 and 1.36 µg/m^3, respectively, using daily measurements as described in Chapter 12.

6.2 Trends

Benzene has decreased from approximately 4 µg/m³ on Jagtvej/1257 in the beginning of this millennium to a value below the lower assessment threshold of 2 µg/m³ (EC, 2008). In 2010, the annual averages were 1.3 and 1.4 µg/m³ at the two urban street stations in Copenhagen (1103 and 1257). Toluene shows a similar trend, and annually averages were 3.4 and 3.7 µg/m³ on the same urban street stations. The main reasons for the significant decreases of benzene and toluene are reductions of the emissions from gasoline-fuelled traffic due to increased use of catalysts and higher ratio of diesel cars.

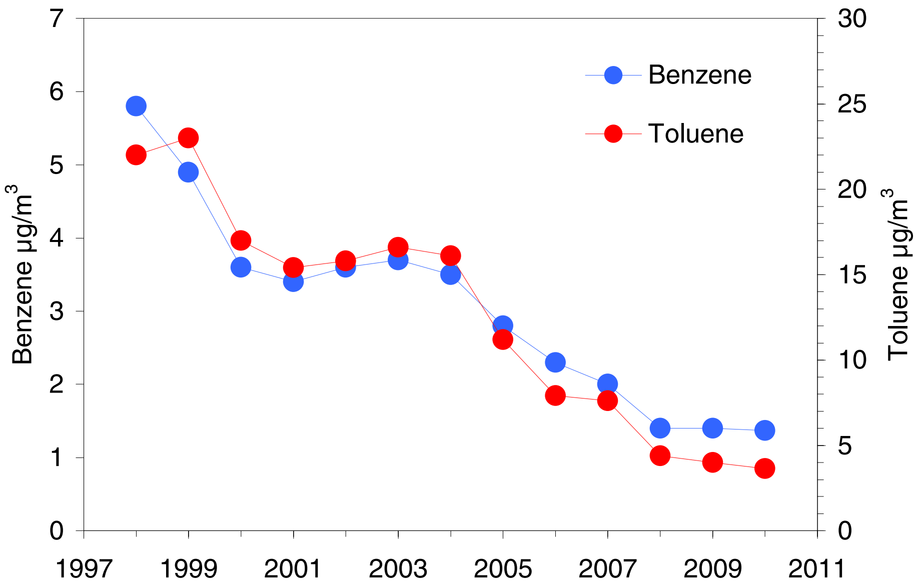


Figure 6.1. Annual average concentrations of benzene and toluene on the street station Jagtvej, Copenhagen/1257.

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

7.1 Particle 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). Measurements with this instrument have 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.

Measurements of particle numbers have been carried out since 2002 in cooperation between the monitoring programme and research projects financed by the Danish Environmental Protection Agency. The measurements have been carried out using a Differential mobility particle sizer (DMPS) that counts particle with mobility diameter between 6 and 700 nm.

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 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 using TEOM and a correction factor of 1.3 may therefore have considerable uncertainty.

Table 7.1. Annual statistics for PM_{10} in 2010. All parameters are calculated as diurnal averages at ambient temperature and pressure.

Unit µg/m^3	Number of results	Average	Median	Days above 50 µg/m^3	90 percentile	Max. day
Traffic						
Copenhagen/1103	330	28	26	10	41	77
Copenhagen/1257	345	27	24	18	42	89
Århus/6153	361	25	23	14	40	76
Odense/9155	318	26	23	16	41	96
Urban background						
Copenhagen/1259	351	19	17	3	30	60
Rural						
Lille Valby/2090	212	20	17	3	34	66
Keldsnor/9055	319	16	14	3	29	86
Limit values (2005)	>329	40		50		

Table 7.2. Annual statistics for $PM_{2.5}$ in 2010. 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	329	17	15	29	72
Copenhagen/1257	339	18	15	30	72
Århus/6153	335	15	13	28	70
Aalborg/8151	323	18	16	34	68
Urban background					
Copenhagen/1259	277	13	11	25	56
Århus/6159	350	14	11	25	59
Aalborg/8158	329	17	15	29	72
Rural					
Lille Valby/2090	310	13	11	24	60
Limit value (2015) (parenthesis gives proposed value for 2020)	>329	25(20)			

Table 7.3. Annual statistics for PM_{10} measured in 2010 using TEOM. The values are calculated based on diurnal averages.

Unit µg/m^3	Number of results	Average	36th highest result	90 percentile	Average times 1.3	36th highest times 1.3	90 percentile times 1.3
Traffic							
Copenhagen/1103	191	26	33	36	33	43	47
Urban background							
Copenhagen/1259	317	12	18	18	16	23	24
Limit values	>329	-	-	-	40	50	

Table 7.4. Annual statistics for $PM_{2.5}$ measured in 2010 using TEOM. The values are calculated based on diurnal averages.

Unit µg/m^3	Number of results	Average	90 percentile	Average times 1.3
Traffic				
Copenhagen/1103	301	13	20	17
Urban Background				
Copenhagen/1259	337	9	15	12
Rural				
Lille Valby/2090	178	9	16	12
Limit value (2015) (parenthesis gives proposed value for 2020)	>329	25(20)		

Table 7.5. Annual statistics for particle number. Average is based on ½-hourly averages. Total annual number of ½-hours is 17520.

Unit µg/m^3	Number of results	Average
Traffic		
Copenhagen/1103	5611	15872
Urban Background		
Copenhagen/1259	8795	6812
Rural		
Lille Valby/2090	11033	3765

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 $\mu g/m^3$) 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 for 2010 were at the same level as for 2009 indicating that the impact of the new asphalt continued.

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, 2009 and 2010 show that the average exposure indicator (EC, 2008) is 14 $\mu g/m^3$. The average exposure indicator is defined as the average urban background concentration measured as average for 2008-2010. In Denmark the average exposure indicator is measured in urban background at Copenhagen/1259, Århus/6159 and Aalborg/8158).

The measurements of particle number show a significant reduction in particle number in ambient air. On HCAB the number of particles has decreased by a factor of about 2 during the period 2002-2010. At the urban background station (HCOE) and rural background station (LVBY) a reduction in particle numbers was also observed though the decrease is smaller than at HCAB. The decreases are only 30% and 15% at HCOE and LVBY, respectively. More details about particle number can be found in Massling et al. (2011).

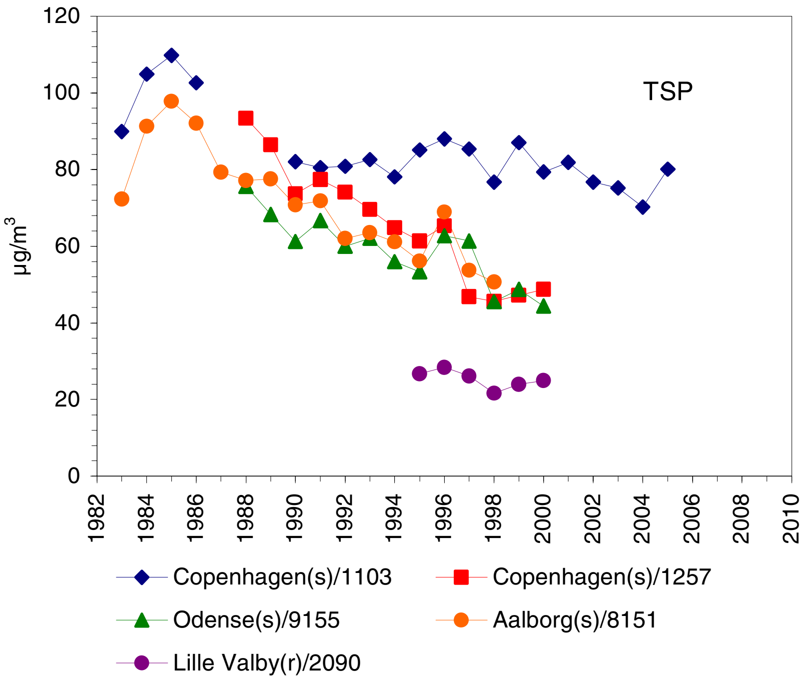


Figure 7.1. Annual averages for TSP measured at street stations (s) and at rural background station (r).

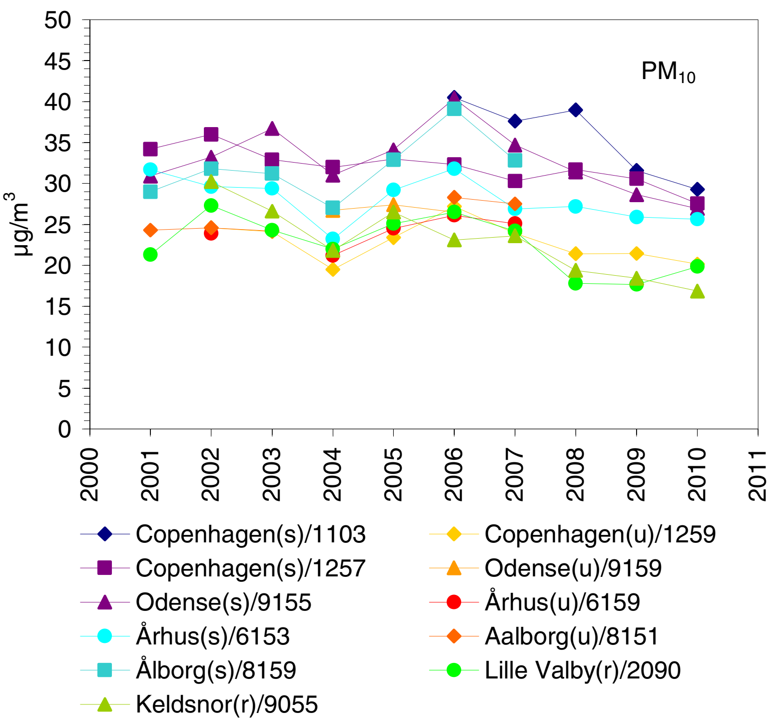


Figure 7.2. Annual averages for PM_{10} measured at street stations (s), urban background stations (u) and at rural background stations (r). The change from gravimetric determination to the use of β-measurements from 2006 gives rise to a 5-10% increase due to the shift of method. The value for PM_{10}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

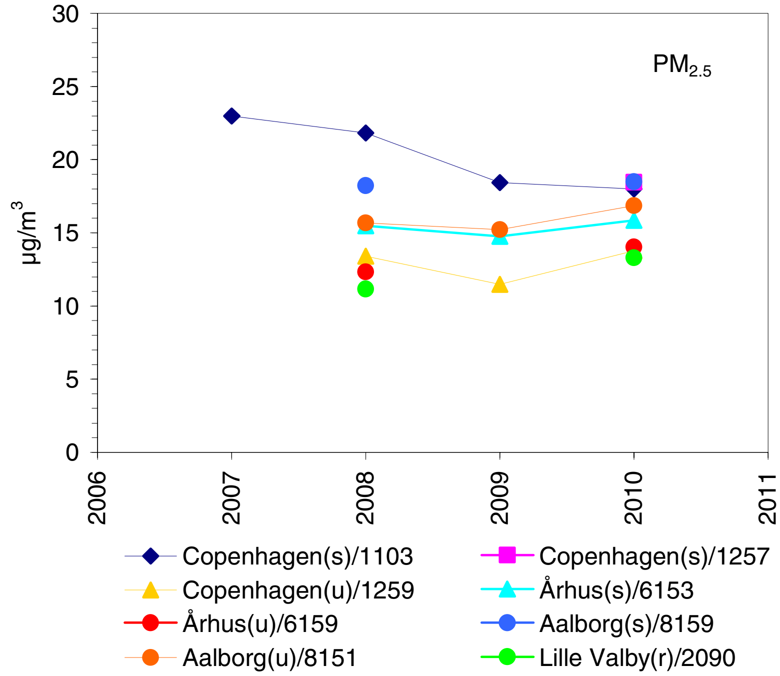


Figure 7.3. Annual averages for $PM_{2.5}$ measured at street stations (s), urban background stations (u) and at rural background station (r). Only annual averages covering more than 2/3 of the years are shown. Data are given at standard temperature and pressure (0ºC and 1 atm.). The difference between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

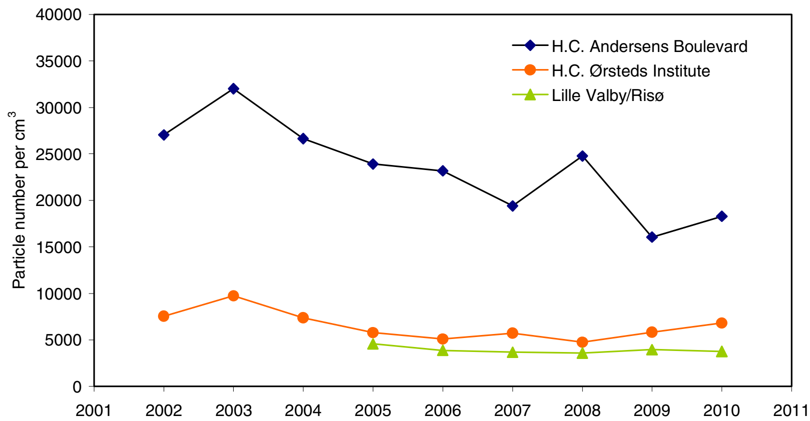


Figure 7.4. Annual averages for particle number. Data for H.C. Andersens Boulevard represents an estimate where annual averages have been corrected for missing data based on comparison with measurements of NOx. This estimate is further described in Massling et al., (2011).

7.4 Subtraction of salt from winter salting and sea

The EU air quality directive (EC, 2008) gives the member states the possibility to subtract the contribution from sea salt and winter salting from PM_{10} before the measured PM_{10} is compared to the limit values. On this back ground the monitoring program is expanded with analysis of sodium at the street stations H.C. Andersens Boulevard, Copenhagen (1103), Odense (9155) and Aarhus (6153) and at urban background in Copenhagen (H.C. Ørsteds Institute/1259). Table 7.5 gives the annual average concentrations for sodium and estimate for total salt (NaCl) in

2010. PM10 has so far not been corrected for the contribution from salt because there were no problems with exceedances of PM10 in 2010.

Table 7.5. Annual statistics for sodium and estimate of total salt (NaCl) in 2010.

	Na ($\mu g/m^3$)	NaCl ($\mu g/m^3$)
Traffic		
Copenhagen/1103	1.0	2.5
Odense/9155	1.0	2.6
Århus/6153	1.0	2.6
Urban background		
Copenhagen/1259	0.6	1.5

The measurements of sodium are carried out with daily averages. This is among other things due to the limit value for PM_{10} based on daily averages that requires subtraction of the contribution from salt on a daily basis. Figure 7.4 shows the results from measurements of sodium at the street station H.C. Andersens Boulevard, Copenhagen (1103) and at urban background in Copenhagen (H.C. Ørsteds Institute/1259). The high concentrations at the street station during the first 2½ months are due to winter salting of the roads. The high correlation between the sodium concentrations for the remaining part of the year is due to long range transport of sea salt that have equal impact on the two stations.

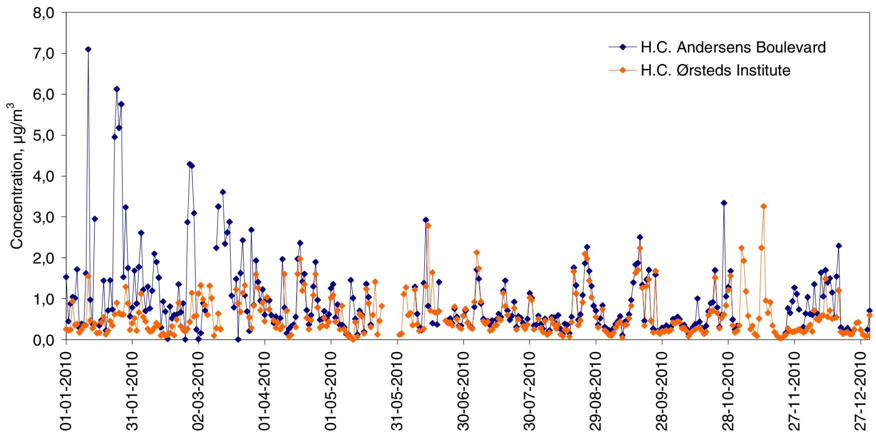


Figure 7.4. Daily concentrations of sodium at H.C. Andersens Boulevard, Copenhagen (1103) and at urban background in Copenhagen (H.C. Ørsteds Institute/1259).

8 Heavy Metals

8.1 Measurements of Heavy Metals

Collection of PM_{10} are performed on filters which can be used for chemical analysis. Selected filters are analysed by ICP-MS (Inductively Coupled Plasma Mass Spectrometry) for their content of elements. Results are presented below (Table 8.1). Comparison between results from the new analysis method and the previously used PIXE-method (Proton Induced X-ray Emission) showed only minor changes in the annual averages, when the low concentration levels are taken in to account.

The table presents also results for analysis of heavy metals in total suspended particulate for second half year of 2010. The content of these heavy metals in PM_{10} and TSP are approximately equal since these metals are mainly found in the fine fraction.

The ICP-MS 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 small.

8.2 Annual statistics

Table 8.1. Annual statistics for Nickel (Ni), Arsenic (As), Cadmium (Cd) and Lead (Pb) measured in PM_{10} during 2010. For comparison the table includes also results for these heavy metals measured in total suspended particulate (TSP) at the rural background station Risø. 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.

Unit: ng/m^3	Ni	As	Cd	Pb
PM10, Traffic				
Copenhagen/1103	2.4	0.8	0.5	5.3
Odense/9155	2.0	0.8	0.4	4.2
Århus/6153	3.1	0.6	0.3	3.0
PM10, Urban background				
Copenhagen/1259	2.0	0.6	0.4	3.5
TSP, Rural background				
Risø*	1.0	0.6	0.4	2.7
EU limit value				500
EU Target values	20	6	5	
Guideline value (WHO) *)			5	
Life time risk level at $1:10^5$ (WHO) **	25	6.6		

*) Only measurements for the second half year of 2010.

**) 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 2010. Measured at Råö in southern Sweden by the Swedish Environmental Research Institute.

Unit: ng/m^3	Total Gas Hg (ng/m^3)	Total Particles Hg (ng/m^3)
Råö (SEOOO14)	1.5	0.007

8.3 Trends

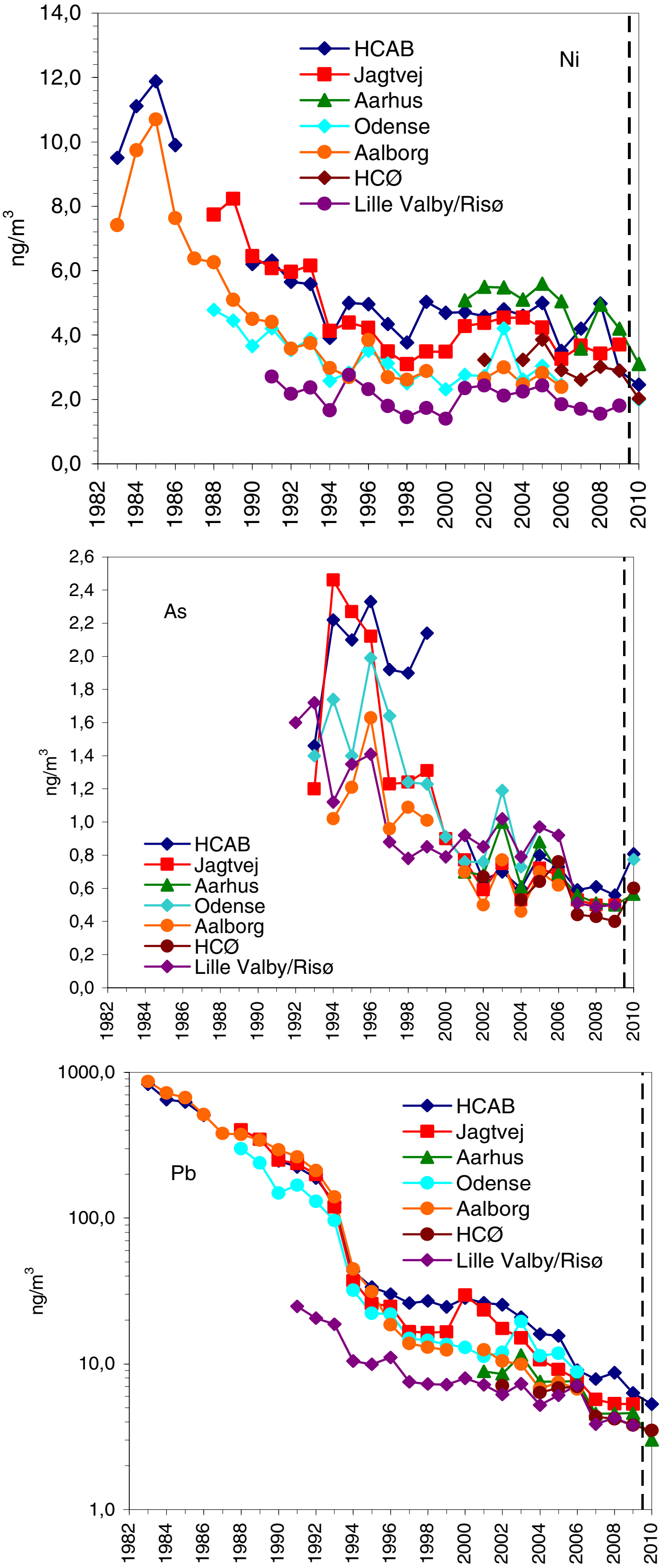


Figure 8.1. Annual averages from selected stations for some heavy metals in particulate matter. Until 2000 in TSP and later in PM_{10} – except for Copenhagen/1103 where PM_{10} replaced TSP from the beginning of 2006. The heavy metals are usually found in fine particles, which make the TSP and the PM_{10} values comparable. Note that the scale for Pb is logarithmic. The dashed line indicate that the analysis method has been changed from 2009 to 2010.

9 Sulphur dioxide

9.1 Annual statistics

Table 9.1. Annual statistics for SO_2 in 2010. 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/m^3	Number of results	Average year	Average winter	Median	98-percentile	Max. Hour	4th highest diurnal mean
Traffic							
Copenhagen/1103	7347	4,9	4,3	3,7	15,9	39,4	13,8
Aalborg/8151	7955	2,6	3,3	2,0	10,4	21,9	8,1
Limit values	>7467	20	20			350	125

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

Number of informations to the public due to exceedance of the alert threshold for SO_2 (one hour average 500 µg/m^3) in 2010: 0.

9.2 Trends

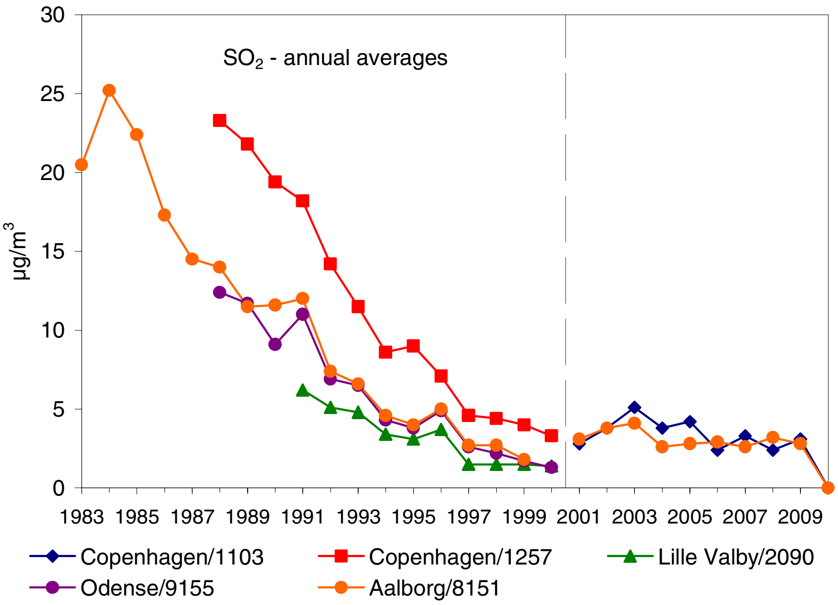


Figure 9.1. Annual averages for SO_2. Until 2001 the results were obtained using KOH impregnated filters for collection of SO_2. These measurements ceased in 2000. After 2000 the SO_2 measurements have been carried out using SO_2-monitors in order to monitor episodic results. The detection limit for 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.

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 with dichloromethane and cleaned up on silica. Before extraction, the filters are spiked with deuterium-labelled PAH.

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 10 PAH's are analyzed in the method.

10.2 Results

The average concentration of benzo[a]pyrene measured in Copenhagen was 0.34 ng/m^3 in 2010. 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, 0.32 ng/m^3; benzo[b]fluoranthene, 0.82 ng/m^3; benzo[j+k]fluoranthenes, 0.23 ng/m^3; indeno[1,2,3-cd]pyrene, 0.45 ng/m^3; dibenzo[a,h]anthracene 0.07 ng/m^3. It should be noticed that the annual average values in 2010 are slightly higher than in 2009. This is most probably due to the fact that the contribution of two winter months (January and February) was missing in 2009. Since PAH concentrations are relatively higher in winter, the lack of these data had contributed to lower average annual values of PAH in 2009 respect to 2010.

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 concluded that the target value for benzo[a]pyrene on 1 ng/m^3 was not exceeded in 2010.

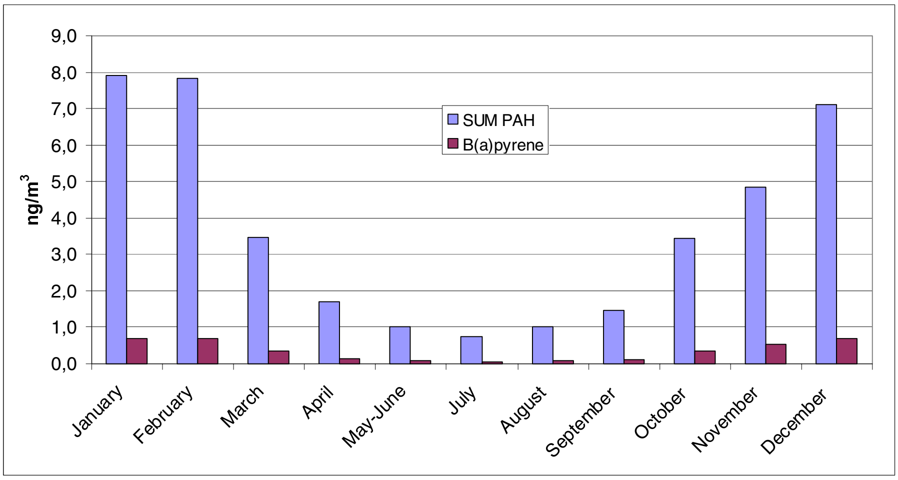


Figure 10.1. Monthly average concentrations in 2010 of benzo[a]pyrene and the sum of the analysed PAH.

Table 10.1. Daily minimum, maximum and average monthly concentrations (ng/m^3) of benzo[a]pyrene during 2010.

Month	Minimum conc.	Maximum conc.	Average conc.
January	0.08	1.78	0.69
February	0.12	3.06	0.70
March	0.10	0.69	0.35
April	0.05	0.37	0.14
May-June	0.03	0.28	0.07
July	0.03	0.44	0.05
August	0.01	0.52	0.08
September	0.06	0.54	0.12
October	0.05	1.24	0.36
November	0.11	1.09	0.53
December	0.07	1.98	0.69
Annual	0.01	3.42	0.34

10.3 Trends

PAH has been measured since 2008 at H.C. Andersens Boulevard. The annual averages of benzo[a]pyrene are 0.40, 0.25 and 0.34 µg/m^3 for 2008, 2009 and 2010, respectively. This indicates a small decrease in the annual averages although with high year to year variations. However, longer time series are needed in order to show whether or not this tendency is persistent.

11 Organic carbon and elemental carbon

Organic Carbon (OC) and Elemental Carbon (EC) are measured on a busy street in Copenhagen (H.C. Andersens Boulevard/1103) and at a semi-rural background site north of Roskilde (Lille Valby/Risø) approximately 30 km west of Copenhagen. Aerosol particles are sampled on tandem filters (quartz-behind-quartz to correct for positive artifacts) and analyzed for OC and EC by a thermal/optical method according to the EUSAAR2 protocol.

11.1 Annual statistics

The measurements of Organic 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. The measurements at H. C. Andersens Boulevard/1103 have been partly suspended in 2010 due to lack of low volume samplers.

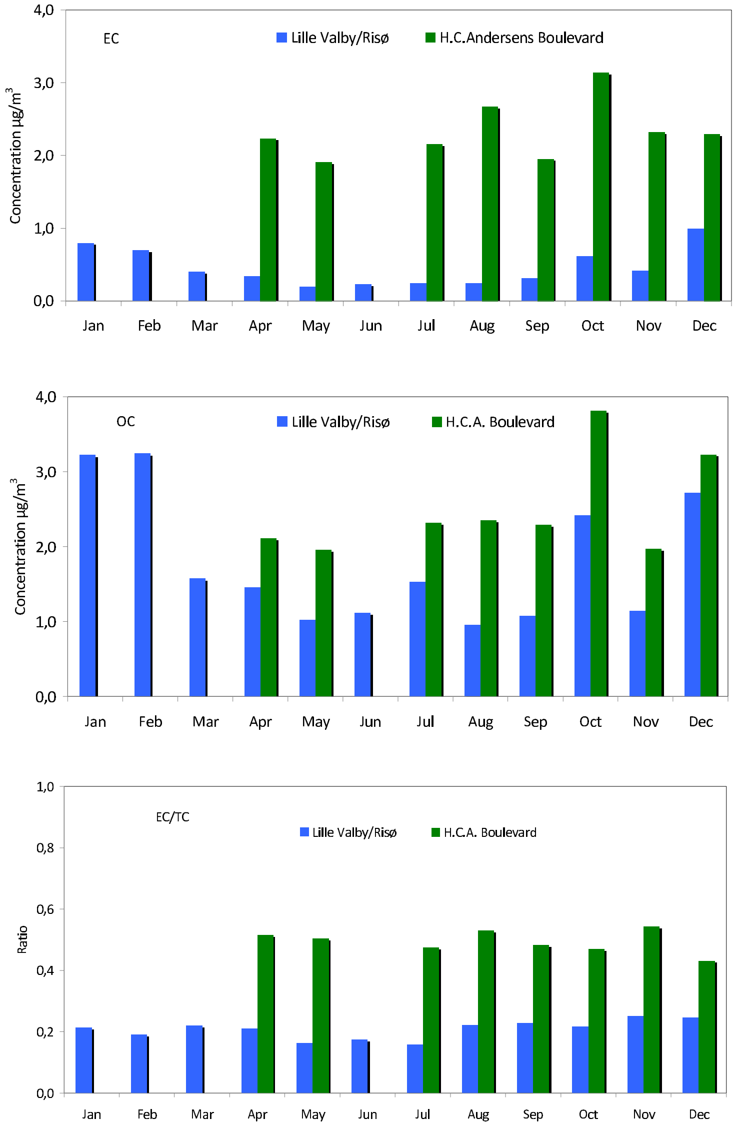


Figure 11.1. Elemental carbon (EC), organic carbon (OC) and the ratio between organic carbon and total carbon (OC/TC) at H.C. Andersens Boulevard (Copenhagen/1103) and in semi rural background at Lille Valby/Risø in 2010.

The ratio of EC to total carbon (TC), and the absolute concentrations on Lille Valby/Risø and H. C. Andersens Boulevard differ markedly: EC is a major component at the urban street station (50% of total carbon) as compared to 21% at Lille Valby/Risø (Figure 11.1). The EC concentration is about 5 times higher at H.C. Andersens Boulevard than at Lille Valby/Risø in 2010. OC concentrations were comparable during winter at the two stations, while summer OC concentrations are lowest at Lille Valby/Risø.

Table 11.1. Annual statistics for OC in 2010. The values are based on daily averages at H. C. Andersens Boulevard (Copenhagen/1103) and in semi-rural background (Lille Valby/ Risø)

Unit: µg/m^3	Number of results	OC, average	90% percentil
Copenhagen/ 1103	191	2.55	4.17
Lille Valby/ 2090	323	1.81	3.92

Table 11.2. Annual statistics for EC in 2010. The values are based on daily averages at H. C. Andersens Boulevard (Copenhagen/1103) and in semi-rural background (Lille Valby/ Risø)

Unit: µg/m^3	Number of results	EC, average	90% percentil
Copenhagen 1103	191	2.39	3.61
Lille Valby/ 2090	323	0.46	0.96

A clear annual variation was observed for EC and OC at the rural background with minimum summer concentrations and higher winter concentrations, whereas the EC/TC ratio showed a slightly increasing trend throughout the year. However, longer time series are necessary in order to determine the seasonal variations. An annual variation is less clear for the street station, where data for the first three months are absent.

12 Ozone precursors

Measurements of 16 selected ozone precursors were initiated in 2009 on the H.C. Ørsteds Institute, Copenhagen/1259, and at Lille Valby/2090 in Roskilde approximately 30 km west of Copenhagen. However, as a result of the revision of the monitoring only measurements at the H.C. Ørsteds Institute has been continued in 2010. In the urban background, ambient air is sampled as 24-hour averages on adsorbent tubes and analysed using thermal desorption gas chromatography mass spectrometry. The major ozone precursors are the aromatic compounds: benzene, toluene, ethylbenzene, xylenes and trimethylbenzenes (TMB), which are routinely measured at the busy street stations in Copenhagen, and the linear C_5-C_7 alkanes: pentane, hexane and heptane. The more reactive unsaturated compounds are less abundant.

12.1 Annual statistics

The urban background concentration of the major ozone precursors benzene and toluene are 56% and 39% of their concentration in the busy streets 1103 and 1257, respectively. Furthermore, the urban background toluene/benzene ratio is smaller than in the busy streets dominated by traffic, i.e. 1.8 versus 2.6, which reflects different sources to benzene and toluene, and a faster atmospheric decomposition of toluene.

Table 12.1. Annual statistics based on daily averages for selected ozone precursors in urban background measured on H.C. Ørsteds Institute, Copenhagen/1259.

Unit µg/m^3	observations	average	90% percentile
benzene	217	0.75	1.85
toluene	214	1.36	2.48
ethylbenzene	218	0.28	0.57
m,p-xylene	214	0.39	0.78
o-xylene	214	0.41	0.98
1,3,5-TMB	210	0.10	0.27
1,2,4-TMB	210	0.34	0.77
1,2,3-TMB	207	0.09	0.21
isoprene	200	0.03	0.07
1-pentene	184	0.04	0.07
trans-2-pentene	204	0.02	0.05
n-pentane	211	0.53	1.05
n-hexane	216	0.19	0.36
n-heptane	216	0.28	0.62
n-octane	217	0.08	0.18
isooctane	212	0.10	0.23

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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 ammonium nitrate.

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.

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THE DANISH AIR QUALITY MONITORING PROGRAMME

Annual Summary for 2010

The air quality in Danish cities has been monitored continuously since 1982 within the Danish Air Quality Monitoring 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 2010 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 only one street station (H.C. Andersens Boulevard) in Copenhagen NO_2 was found in concentrations above EU limit values while NO_2 in Odense, Aarhus and Aalborg was below the limit value. Model calculations indicate exceedances of NO_2 limit values at several streets in Copenhagen. Both PM_{10} and $PM_{2.5}$ were below limit values at all stations. 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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